MIT/LCS/TR-301

CREATING A COMPUTER BASED LEARNING ENVIRONMENT FOR PHYSICALLY HANDICAPPED CHILDREN

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CREATING A COMPUTER-BASED LEARNING ENVIRONMENT FOR PHYSICALLY HANDICAPPED CHILDREN

by

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Submitted to the Department of Mechanical Enginnering
on August 5, 1983 in partial fulfillment of the
requirements for the Degree of Doctor of Philosophy

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Abstract

The objective of the research is to develop a computer-based learning environment for children physically handicapped by cerebral palsy and to study several issues related to the use of this environment for diagnostic, educational, and remedial purposes. The study is motivated by the desire to better understand the intellectual and motoric deficiencies of cerebral palsied children and to use this information in the development of teaching methods to accommodate each child's particular needs. The aim of the thesis is to present a model for the use of computers with cerebral palsied children, thus enhancing the capacity of the computer as an effective and versatile educational tool, as well as an invaluable instrument in the diagnosis and remediation of the intellectual deficiencies these children may have.

Cerebral palsied children were selected because they have a disorder of movement and posture due to permanent but nonprogressive lesions of the brain occurring prior to the end of the first year of life. They are known to have a cognitive retardation as the result of either reduced interactions with the environment due to their physical handicap, or brain lesions, which may affect motor areas as well as areas of the brain that support specific intellectual functions. However, these children's motor impairment makes understanding and evaluating their cognitive deficiencies quite difficult. It is difficult to create interesting and challenging activities that these children can perform in order to evaluate their intellectual abilities. The computer provides the means with which these children can perform these activities.

The research can be divided into two studies. One study consisted of developing a general purpose computer system for implementing a wide variety of performance tasks. The aim of this system was to minimize the motor component involved in performance. The seriation task was implemented in this system and used to investigate how cerebral palsied children of different ages and physical impairments solve this task. The results of this study indicated that: (a) there is a great discrepancy between the age of the cerebral palsied children and normal children who were able to perform the task; and (b) the strategies to solve the task used by cerebral palsied children were not different from the strategies used by normal nonhandicapped children. This suggests that cerebral palsied children's ability to perform the seriation task is delayed rather than distorted.

The other study, which was the major part of the research, was an in-depth study using Logo to explore the nature of cerebral palsied children's intellectual deficiencies, and whether these deficiencies could be minimized by providing these children with the means to develop Logo computer activities. Three cerebral palsied subjects from the Cotting School for the Handicapped Children participated in this study. The results demonstrated that combining information from a variety of Logo activities provided a powerful way of making a fine-grain analysis of performance in spatial, numerical, and writing domains. The Logo activities these children developed also had educational and remedial purposes. With the computer these children developed activities that helped them to improve their understanding of concepts in geometry and mathematics; acquire knowledge about problem solving such as planning, setting up goals, breaking goals into simpler subgoals, abandoning plans that do not work, and debugging their plans; and improve their writing skills. The computer provide also a way for these children to perform remedial activities especially designed to help them to overcome particular deficiencies that might be due to their lack of manipulatory experience.

Finally, the observation of cerebral palsied children's activities offered a magnified and "slowed-down" view of the learning process, making possible the identification of the components of a successful learning environment. The work with the handicapped serves to illustrate in a concrete way a series of principles that can be used to create effective learning environments: how learning takes place in a computer-based environment; how the interaction between the student, the instructor, and the computer can help the student to acquire new knowledge; how to identify strengths and weaknesses in the students' thinking process; how to help them to use their strengths to overcome their weaknesses; how and when to intervene in the student's activity to help him to overcome his difficulties without taking control away from the student; and how to design remedial activities to help the student to overcome a specific difficulty or to acquire a particular piece of knowledge.

Thesis Supervisor: Dr. Seymour Papert

Title: Professor of Mathematics and Education

Aos meus pais

Armando Valente
e
Dirce V. Valente

And to my friends

Greg Gargarian
and
Michael S. Murphy Jr.

Acknowledgements

I would like to express my appreciation to the people and organizations who made this work possible. In particular, I would like to thank:

- Professors Seymour Papert and Marvin Minsky for inviting me to come to M.I.T., and for their invaluable inspiration. Special thanks to Professor Papert, my thesis advisor, for his guidance throughout my thesis work.

- Dr. Sylvia Weir for her investment of time and faith in my intellectual development.

- Professor Susan Carey for her introduction to the field of Psychology and her continual support.

- Professor Robert Mann, chairman of my graduate committee, Derek Rowell, and the other members of my committee, Professors Papert, Carey, and Dr. Weir, who gave me the freedom to pursue this research.

- To the people who provided many stimulating discussions about the Logo ideas: Harold Abelson, Howard Austin, Jean Bamberger, Andy diSessa, Gary Drescher, Paul Goldenberg, Robert Lawler, Margaret Minsky, Hermine Sinclair, Cynthia Solomon, and Daniel Watt.

- Ubiratan D'Ambrosio for facilitating my extended absense from the University of Campinas.

- Greg Gargarian whose companionship helped me to make sense of this foreign country, and provided me with a new home. My deep gratitude for many inspiring interactions.

- The Division for Study and Research in Education for providing an encouraging and supportive environment. Special thanks to Professor Benson Snyder and Barbara Nelson.

- Ann Berger, Susan Jo Russell, David Scrimshaw, and David Smith, members of the Educational Computing Group for their supportive friendship.

- William Carmichael, Michael Talbot, James Petros, and the students from The Cotting School for Handicapped Children, for providing an ideal research environment.

- Mary McAuliffe from the Massachusetts Hospital School for allowing me to work with their students.

- Michael Fultz for his exceptional editorial assistance.

- The following institutions which provided financial support for this work: Universidade Estadual de Campinas, Conselho Nacional de Desenvolvimento Cientifico e Tecnologico, Fundacao de Amparo a Pesquisa do Estado de Sao Paulo, Fundacao Judith Buzaid, and the Bureau of the Education for the Handicapped.

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Introduction

Creating Learning Environments for Physically Handicapped Children

Physically handicapped children have motor impairment that limits their capacity to interact with the physical world. Their disabilities can prevent these children from developing motor skills that form the basis of their learning processes, and from performing activities that can help educators and therapists to understand and evaluate their intellectual abilities. The objective of the research that I describe in this thesis is to create a computer-based learning environment to provide these children, specifically those handicapped by cerebral palsy, with the opportunity to develop interesting, challenging, and revealing activities that have an educational, diagnostic, and remedial purpose; activities that can foster a deeper understanding of these children's intellectual abilities, and that can provide these children with a chance to acquire knowledge, a chance to overcome their particular intellectual deficiencies.

The intellectual disorders which are found in physically handicapped children offer interesting material for both theoretical and practical research. However, most of the studies conducted with this population are designed not to describe individuals in detail, but to classify them according to a few variables. Such studies tend to be cross-sectional rather than longitudinal, and tend to lead

to misconceptions about these individuals' deficiencies (Byers, 1971). This lack of understanding has led people to adopt certain beliefs and to behave in certain ways that have a significantly negative impact on handicapped children's intellectual development. For example, it is common to find parents and teachers who say that their physically handicapped child has learning difficulties because "something is wrong with the child's brain." This type of statement can be interpreted as that the chances these children have to learn new things are minimal, regardless of therapy. This is frequently not true.

It is important to mention that in some cases brain lesions can, in fact, impair learning. The literature on neuropsychology often mentions cases of patients with brain lesions that affect their capacity to retain information and thereby impede learning. However, before we discover what type of brain lesion and what kind of intellectual deficiencies a physically handicapped child has, we should not let the possibility of brain lesion stop us from trying new teaching approaches to help the child improve his or her cognitive performance. We should not let a simplistic view of the child's difficulty constitute a barrier that contributes to the perpetuation of the intellectual stagnation that some physically handicapped children may suffer. Before we feel hopeless we should consider that there may be other causes that contribute to handicapped children's intellectual deficiencies. They may, for example, have behavior deviances, not necessarily directly related to brain injury, that block them from having a positive attitude towards learning or, indeed, any constructive activity. Handicapped children are frequently unable to communicate adequately or to move within their environment; they cannot easily direct or effect changes in their environment, and thus, their actions are constrained by a situation which, to them, is completely negative. This may lead to the development of a poor self-concept and to the despairing attitude that no matter what they do they will always feel disadvantaged compared to a normal child. Another reason for the common intellectual underdevelopment among handicapped children might be the overprotection they receive from people who deal with them. This places the physically handicapped in a convenient position since they have others doing things for them; they do not have to think, they do not have to do anything, they know that

someone will do everything for them. And, we often confirm this expectation. [1]

The first thing we see when we approach a physically handicapped person who is trying to do something on his own is the heroic struggle this person goes through in order to accomplish the task. Our immediate reaction is to help. With the best of intentions we help by fulfilling all his requests. We are motivated by the affective aspect of the human relationship and become trapped in that role. Our tendency is not to consider a more effective way to help, nor to provide that person with the means to overcome his physical problems in order to be more independent. Instead, we create dependency. We do not help the handicapped person to solve his problem -- instead we get rid of the problem. We may do this because either we do not want to investigate the problem more deeply, or we may, in fact, create this dependency in order to feel useful and needed.

To show how this situation can become complex, I was once approached by a teacher who said that I did not need my "computer paraphernalia" to teach the physically handicapped, what I needed was "to love them." When I asked her what she would do if her students told her they wanted to write or draw something, she said that if their physical handicap prevented them from doing it she would write or draw for them. It is interesting that it never occurred to her that, possibly, her students were not interested in the final product but rather in the act of producing the drawing or the writing for themselves. Her "love" was preventing her from finding ways in which these children would be able to accomplish certain tasks on their own. Her attitude was helping to create an artificial world in which the children did not have to do anything for

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1. Many parents of handicapped children acknowledge that they overprotect and pamper their children. Studies of the interaction of mothers and their severely physically handicapped children have shown that the mothers kept their children in a stimulus-deprived environment. The most common admission of this behavior was that, "He misses so much in life that I try to make it up to him" (Cruickshank, Hallaran, and Bice, 1976a). Shere and Kastenbaum (1966) studied the interaction of mothers and their severely cerebral palsied children by interviewing them and observing their behavior. In general, they found that these parents did not seem to be aware of the importance of attempting to improve their child's cognitive development by providing them with the opportunity to initiate and control activities. By the time parents realize that by doing everything for their child they have contributed to the handicap, the child has learned to enjoy his dependence on others and will not willingly relinquish this status.

themselves, but rather direct other people to think and to do things for them. She was not helping her students to overcome their physical handicap. Instead, she was helping them to become even more handicapped, not only physically but mentally as well.

I am not arguing that we stop aiding the handicapped, nor that we should not "love" them. My proposal is that we create learning environments with the appropriate tools so that handicapped children can actively initiate and control the activities they want to develop. Through this sort of engagement we can understand their intellectual deficiencies and begin to overcome them. Before dismissing these children, or overprotecting them, we must develop ways to understand both the nature of their disabilities and their capacities. Only then will we be in a position to learn about each child's unique intellectual strengths and weaknesses, and to help them to use their strengths to overcome their weaknesses.

Two fundamental ideas run through this thesis. First, it is possible and desirable to create learning environments so that the physically handicapped can have the opportunity to develop activities which directly tap their intellectual abilities. Second, the possibility of learning about different knowledge domains, of learning about other people, and of learning about themselves can change the way handicapped children see themselves, and the way they are seen by other people -- it can open the door to a bright new future. We are learning how to create learning environments not only to overcome cognitive deficiencies but also to change a hopeless situation into a promising one. By helping physically handicapped children to "untrap" their minds we can see that behind their struggle with the physical world there is a human being willing to do things, to improve, and to be independent.

The learning environment that I propose has two important ingredients, children and computers. Children are seen as builders of knowledge using the material found in their surroundings, and the computer is seen as a tool that has the function of helping the physically handicapped to gain access to the material in the learning environment.

The idea that children are builders of their own knowledge was proposed by Jean Piaget, who observed that pre-school children acquire a vast quantity of knowledge without being taught. For example, Piaget observed that children both learn to speak, and learn spatial concepts needed to move around in space, without any formal teaching, without any curriculum. However, the idea that children have the capacity to build their own knowledge poses an interesting problem in view of the fact that certain forms of learning do not take place naturally. Children need formal instruction to learn certain concepts in science, in mathematics, and so on. The question then becomes, "Why do some forms of learning take place spontaneously while others are delayed by many years or never happen without formal instruction?"

Piaget's explanation to the slower development of certain concepts is their greater complexity or formality. Another explanation is offered by Seymour Papert. In his book Mindstorms, Papert suggests that if children are builders, they need materials to build with, materials found in their surrounding cultures. He points out that in some cases the culture supplies them in abundance, thus facilitating natural learning. For example, the fact that so many things come in pairs (parents, shoes, socks, etc.) is material for the construction of the concept of numbers. Other forms of learning are delayed or do not happen at all because the child's culture does not supply the material needed to make certain concepts simple and concrete. Papert proposes that natural learning can still take place when we create environments which contain plenty of materials for the child to build knowledge.

The learning environment that Papert has created is the Logo environment; Logo being the computer language to communicate with the "Turtle," a computer-controlled cybernetic "animal."[1] The Turtle is one of the objects the child programs by using the Logo language. It is an interesting object for the child to play with, an object which can enhance the child's intellectual

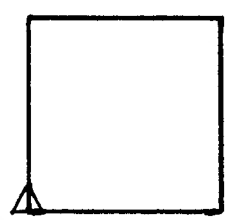
1. Henceforth, the term "Logo environment" will refer to the learning environment consisting of computers, children, computer activities, programming ideas, and several learning principles, proposed by researchers who have used Logo. The term "Logo commands" will referred to the computer language to instruct the Turtle.

curiosity. To act upon that natural curiosity the child has to use concepts found in geometry, computer programming, and problem solving -- the Turtle becomes, then, the material the child uses to build knowledge.

There are two kinds of Turtles in the learning environment: the floor Turtle, a physical object which moves on the floor and looks like a round, plastic-glass covered mechanical toy on wheels with a pen under its belly; and the graphic Turtle, which looks like a small triangle and moves on the computer TV screen.[1] The Turtle's behavior is governed by commands in the Logo language that change its position or its orientation. The Turtle can move forward and backward in a particular direction, or can rotate about its central axis. As the Turtle moves around it can leave a trace of its path depending upon whether or not the pen is down or up.

The child's first encounter with the Turtle begins by showing how the Turtle can be made to move by typing Logo commands on the computer keyboard. FORWARD 100 moves the Turtle in a straight line a distance of 100 Turtle steps. Typing RIGHT 90 causes the Turtle to rotate around its axis 90 degrees. Typing PENDOWN causes the Turtle to lower its pen and PENUP instructs it to raise its pen. As the child explores these commands he learns how to combine them to draw a picture. He learns that the numbers used as input commands cannot be arbitrary but that there is a relationship between what he wants the Turtle to do and the number he selects. For example, to draw a square -- size 50 -- the commands one might use are:

```
PENDOWN
FORWARD  50
RIGHT  90
FORWARD  50
RIGHT  90
FORWARD  50
RIGHT  90
FORWARD  50
RIGHT  90
```

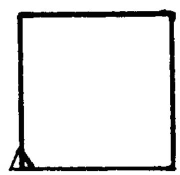


Initial and final positions of the Turtle

1. In the explanation that follows the term Turtle will refer to the floor turtle. It is a concrete object that moves in space. This makes easier to conceptualize its movement, position in space, than the Turtle on the computer TV screen.

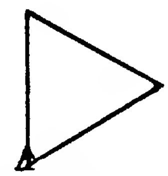
The child also learns that he can program the Turtle to respond to new commands. This is simply done by "teaching" the Turtle a new word which the child invents. For example, the sequence of commands to draw the above square can be turned into a procedure by telling the Turtle how TO SQUARE. The same can be done to teach the Turtle to draw a triangle.

```
TO SQUARE
FORWARD 50
RIGHT 90
FORWARD 50
RIGHT 90
FORWARD 50
RIGHT 90
FORWARD 50
RIGHT 90
END
```



Initial and final positions of the Turtle

```
TO TRIANGLE
FORWARD 50
RIGHT 120
FORWARD 50
RIGHT 120
FORWARD 50
RIGHT 120
END
```

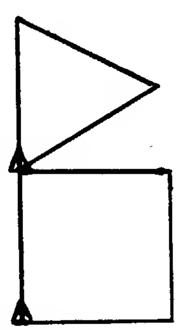


Initial and final positions of the Turtle

Once this is done the procedures SQUARE, and TRIANGLE become part of the repertoire of commands the Turtle is able to "understand." They can be subsequently used to define other procedures, such as the procedure to draw a HOUSE -- a triangle on top of a square. If we use the SQUARE and the TRIANGLE procedures to draw the house, we get:

```
TO HOUSE
SQUARE
FORWARD 50
TRIANGLE
END
```

Final position of the Turtle



Initial position of the Turtle

The idea of how to draw a house may be correct but the results may not correspond to what the child expected. The square and triangle may not, for example, be positioned relative to each other to produce a house. This sort of difficulty is called a "bug" in the Logo culture. This bug can be

easily "debugged" by following each step used in the definition of the procedure HOUSE until the problem is detected and fixed.

In the Logo learning environment the floor Turtle as a drawing device is not the only object the child can use to play or to enhance his intellectual curiosity. Some floor Turtles have touch sensors which can be used to program the Turtle to seek out or to avoid obstacles; or the child can use the screen Turtle to draw pictures in color that move on the computer screen; or the child can program the computer, in the same way the Turtle is programmed to play music. With each of these activities the child is learning how to use and control a collection of "materials" with which to build knowledge. The child is learning mathematical concepts -- concerning numbers, angles, and shapes -- and is learning important ideas about problem solving. Each procedure the child defines becomes an entity that describes a thinking process, which can be debugged and used to solve more complex problems. All these kinds of learning are taking place naturally because the activities, and the means to develop them -- that is, the material found in this computer environment -- have mathematical and problem-solving properties which the child masters by manipulating them, rather than them being formally taught.

Why do we want to make the Logo environment available to physically handicapped children?

The idea of creating learning environments for physically handicapped children is not new. Typically, however, the term "learning environment" when used in the literature on the physically handicapped refers to the type of school or classroom arrangement (Cruickshank, 1975). The recommendations that educators and clinicians suggest are based on the idea that handicapped children should be served in learning environments that best meet their special needs. These "special needs" are determined by an assortment of psychological tests that reflect a particular theoretical framework. For example, William Cruickshank has found that cerebral palsied children have attention deficiencies characterized by forced responsiveness to stimuli. According to Cruickshank (1976a), this deficit operates to the child's detriment in any situation in which the required behavior calls for attention or concentration. Further, based upon his

experimental findings Cruickshank (1976b) has suggested that the learning environment for these children be as free from stimulation as possible. The same idea of reducing external stimuli is carried into the preparation of learning materials. Cruickshank suggests that the best reading books for cerebral palsied children should be the ones in which pictures are deleted or reduced in stimulation value. The activities these children should develop are also designed based upon deficiencies found in psychological tests. For example, Marshall (1975) suggests that, if a child has shown deficits in body image concept, the following "activities might be included: drawing pictures of himself, a life-sized tracing on brown paper, color front and back, then cut" (p. 286). Then, she proposes that, "If a child has difficulty manipulating materials, the teacher or aide may help him as he dictates what he wants done" (p. 287).

Cruickshank's and Marshall's ideas of a learning environment seem quite different from the ideas embodied in the Logo environment. The research that I conducted with cerebral palsied children demonstrated that the latter has certain features that makes it a more appropriate learning environment for the physically handicapped. Several qualities of the Logo environment contribute to its effectiveness. First, the Logo environment can be established in a regular classroom. We can have several computers, numerous children using them, and lots of activities, noise and interaction among the children. However, this "stimulation" does not seem to bother them. Video-tapes of these children working on their computers show that despite what Cruickshank would consider distractive activities happening in the background, all the children are able to concentrate on their work and carry it through. The point that I want to stress is that if the child is doing something he is interested in, and committed to, the environment does not need to be as structured and as free of stimuli as Cruickshank has proposed. Second, in the Logo environment the materials the child has to manipulate are not physical objects that require a high degree of motor coordination, as required in Marshall's activities. The objects in the Logo environment are controlled by the computer. The computer is the instrument that helps to minimize the barriers between the child and the physical world by moving the objects around, by doing the drawing and the writing. Instead of asking the teacher or the aide to perform the

desired activities, the child merely has to give commands to the computer in order for it to carry them out. Thus, if the child has sufficient motor coordination to push a button, he can command the computer to do practically everything he wishes without being constrained by motor deficiencies.[1] Third, opposed to Cruickshank's and Marshall's teaching methods, in the Logo environment the activities the child develops are not predetermined. Rather, the child decides what to do and has the control over it. This has an important role in transforming the physically handicapped child's passivity into action. Fourth, in the Logo environment the child's activities do not follow a preestablished structure, as Marshall has stated. Structure, then, does not come from the materials, nor from the teacher, but from the child's own imagination and the activity of programming the computer. The products achieved are of personal interest, and the activity of programming demands a certain structure; if the child does not use the proper sequence of commands to instruct the Turtle the desired result is not produced. Fifth, in the Logo environment emphasis is not placed on the child's product, but on the process by which the child achieves his goals. The instructions the child gives to the Turtle constitute a description of the process of how the Turtle carries out an activity, revealing the steps in the child's thinking, the problem-solving style, and intellectual capabilities. Programming the computer becomes a very powerful diagnostic tool, a window into the child's thought processes, making it possible for us to understand his weaknesses and strengths so we can begin to help the child to develop his intellectual capacities.

In the research that I describe I made the Logo environment available to children severely physically handicapped by cerebral palsy; i.e., people whose motor disability was acquired prior

1. For those children whose typing skills are limited either by lack of motor coordination, or by involuntary movements, I have used the button box. It is a device with fewer keys than the conventional computer keyboard, and these keys are larger and far apart from each other. Each key, called a button, can stand for an arbitrary long string of alphanumerics, typically a Logo command, such as FORWARD 10. New commands can be added either by increasing the number of buttons, or by changing the function of each button.

to the first year of life. [2] I extended the diagnostic capacity of the computer by developing a system with which these children could perform Piagetian tasks on the computer screen, demonstrating how the combination of the computer version of these tasks and the Logo activities can help us to understand what might be the deficiencies characteristic of children with cerebral palsy. In addition, I show how the Logo activities can help these children learn powerful ideas to explore their limits and exercise independent action. These activities have had a significant impact on the children's lives, enhancing their intellectual capabilities, their sense of self worth, and putting them in touch with their own capacities to learn and to develop.

This research started four years ago as part of the "Information Prosthetics for the Handicapped" project developed at the Logo Laboratory at the Massachusetts Institute of Technology. The primary focus of this project was the application rather than the development of new technology. We wanted to learn how the computer could be used to increase the potential of cerebral palsied children. The idea for this project originated from a study that Paul Goldenberg, a member of the Logo Laboratory, developed with several types of handicapped children, including cerebral palsied adolescents (Goldenberg, 1979). His work showed that children previously uninterested in using a prosthesis which had been constructed specially for them -- for example, a headstick for typing -- responded with unexpected and impressive zeal and excitement when given the opportunity to use Logo for drawing, doing graphic animation, and music. These activities revealed that children previously considered to be mentally defective showed a remarkable capacity to accomplish intelligent tasks. Their rate of learning showed no impairment and their experience with the computer demonstrated, for the first time, that some of these children had considerable intellectual abilities. Goldenberg's study lasted for a short period of time and was not designed to explore the long term effect of Logo on the intellectual development of the

2. In the next section I will provide more information about the physical and mental disabilities that cerebral palsied individuals may have.

handicapped. It was a study designed to demonstrate the possibilities of using Logo with physically handicapped children and to open up a new field of investigation.

In view of Goldenberg's results and the success of others working with the Logo environment with normal fifth graders (Howe and O'Shea, 1976; Papert, 1973), with children with learning difficulties (Howe and O'Shea, 1976; O'Brien, 1977), and with an autistic child (Weir and Emanuel, 1976), the Logo Laboratory staff decided to concentrate part of its resources to an indepth study of the use of the computer with cerebral palsied children.[1] The aim of the study was to make the Logo environment available for use by these children, and "to study in this environment a series of issues in developmental psychology, in the psychology of learning, and in methods of instruction" (Papert and Weir, 1978, p. 1).

The research took place at the Cotting School for Handicapped Children in Boston, a vocational school which offers a twelve-year academic program for physically and medically handicapped children with mentally normal capacities. A microcomputer from the Logo Laboratory[2] was set up at the school and I started to work with Mike, a 17-years-old severely cerebral palsied boy, who was enrolled as a tenth-grade student.

Mike was selected as our first subject for several reasons. First, Mike had been at the Cotting School since first grade and had shown a high degree of intellectual abilities: excellent reasoning abilities, excellent memory, and an appreciation of being challenged by difficult tasks. This meant that he could not only exploit the intellectual power of the Logo environment but also help us with feedback in terms of the development of his ideas, instructional techniques we were

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1. The members of the Logo Laboratory involved in this project were: Seymour Papert, director of the Laboratory; Sylvia Weir, responsible for the project; Gary Drescher, research assistant, and myself.

2. The microcomputer used was the 3500 designed by Professor Marvin Minsky of the Artificial Intelligence Laboratory of M.I.T.. This was the first attempt to implement Logo in a small computer. Today the 3500 microcomputer is no longer available and the computer system used at Cotting School is the Apple II microcomputer.

using, and his feelings about the use of the computer. Second, Mike's teachers were concerned that there was a gap between Mike's potential and the school's ability to meet his intellectual needs. Since Cotting is a vocational school, there was a great concern that Mike would graduate without having any perspective for a future career. The possibility of exploring the use of the computer as a learning and working tool was appealing to the school staff, to us, and to Mike, who could not wait to get his hands on the computer.

My work with Mike began in October, 1978. This was the first time I had the opportunity to work with a cerebral palsied individual. Mike had never done any work with computers and his interactions with people outside his family and school circles were limited. This arrangement constituted a unique learning experience for both of us.

My first contact with Mike showed that traditional educational approaches did not work. Although he has sufficient motor coordination to control his electric wheelchair, he had never used a pencil, and there were very few things he could do with his hands. It was clear that I needed to articulate better for myself, as well as for Mike, the nature of his problem and what prohibited him from becoming a more natural learner. The working method that I used with Mike was to let him select the computer activities he would like to develop. The computer was his "scratch pad," on which he would draw things, write, solve algebraic expressions, or keep notes about his programs.[1] I was Mike's experienced colleague performing several roles: an observer trying to understand Mike's difficulties and working style, a facilitator providing the information necessary for him to reach his goal, and a critic asking for better structured and more elegant programs. In this learning environment it was possible to identify several aspects of Mike's working style. On the one hand, if we consider his degree of motor handicap, it was a surprise to discover how much knowledge he had acquired, and how creative and meticulous he was. On the

1. Although Mike has sufficient motor control in his left hand, typing was not very easy. To solve this difficulties he developed an ingenious way of typing: he supported his left hand on the frame of the computer keyboard to inhibit involuntary movements, and pressed the keys with the thumb.

other hand, there were several areas of knowledge that were underdeveloped. Mike's writing skills, for example, was one of these areas. This is a sample of the first piece of writing Mike produced.

> "I ment Dr. Sileva Where, Jose Valente and Gary Drescher on October 5, 1978 at 9 : 32 : 47 AM. which the compuer I was so excized it like being it a waitting & maternace room at a hospital whiting to fine it oot's a boy or a grail.
>
> When I teach I lean form my standt. as well or bedter then form a book. I call that on the job training.
>
> My fist and every day experreance with the compuer when it cash and it lost but it keep on losting all that I have tort it but keep no teaching it overy and overy agian when I bring back to live."

This example looks like spoken English which has been written down. There is much phonetic spelling, omission of words and letters, as well as letters reversed and misconstructions of verb tense. The question immediately arises as to what extent these problems are due to lack of experience or to brain damage. In order to investigate and to try to overcome this problem, we set up a focal remedial program in which an English teacher instituted a series of specific exercises based on weaknesses found in Mike's writing. All the lessons took place in the computer room, using the computer text editor, instead of having someone writing for him. Mike's use of this remedial program resulted in a gradual improvement in his writing, and he is now writing papers at an acceptable level for college freshmen. This indicates that the deficits he has shown may not solely be attributed to brain lesion and opens the possibility that some are due to lack of experience.

The outcomes of Mike's computer work had an immediate impact upon him and upon the school staff. The school's superintendent expressed his view, in a letter he wrote to us on March 12, 1979, as:

> "One of the most important spin-offs has been the demonstration by Mike that confirms our longtime suspicion that he did possess average, or better, intelligence. As you know, Mike's serious speech problem prevented his participation in classroom discussion and verbal testing. Mike's athetoid movements prohibited him from other forms of testing, writing, and

> manipulative exercises. We could only assume, as a result of our observations, that he did possess normal intellectual capacities. Now, however, we have demonstrated evidence that rather proves that we have been underestimating him.
>
> Up until now, Mike has been the quiet kid in the electric wheelchair that "was there". He demonstrated no leadership qualities. Since Project Logo, we have seen a remarkable change in Mike. With the development of these new skills Mike is now "somebody!" He is doing something that no other student (at the school) is doing. He is, for the first time in his life, "top dog!" He has developed a wonderful sense of self-worth, and his personality has improved remarkably. He now has a more positive attitude, has developed poise and shows more confidence in his ability to contribute."

This notable change in Mike's life confirmed Goldenberg's findings and made a remarkable impression on other students. Even younger students in the fourth grade wanted to participate in the project so they could have fun and play with the computer. This generated the opportunity for us to explore the psychological and educational issues in a rather unique way. It created an experimental research environment where everyone -- students, the Cotting staff, and our group -- had something to contribute to and gain from the project. By developing computer capabilities the students were not only learning underlying academic concepts, they were also acquiring a better understanding of their deficiencies and learning to cope with them by developing a more positive attitude -- they were becoming active achievers rather than complacent losers. This change in their view of themselves, together with the skills they acquired, have made a significant impact on their lives. The majority of the high school students who participated in the project are today computer majors in colleges in the Boston area.

So, too, did the Cotting School benefit from the project, acquiring new educational and vocational tools. A computer center has been established and Logo has been included as part of the high school curriculum. Computers were placed in the resource room and Logo has been used for diagnostic and remedial purposes with students who need individualized tutorial attention. Computers have also been brought to the elementary classrooms so these students can have a chance to develop computer activities.

From our point of view we were able to show that the computer can be an effective instrument to

be used with physically handicapped children. It provided us with a way of understanding these children's intellectual disorders so we could be truly helpful to them, giving them a way out of what seemed to be a hopeless situation.

The aims of the thesis is to dissect as far as possible the specific contribution of the computer activities in furthering these children's cognitive and emotional development, to analyze the specific pathways of their improvement, and to understand aspects of the learning process that took place in order to create more effective learning environments for society as a whole.

Chapter 1 provides a review of the literature on cerebral palsy, emphasizing the intellectual disorders of cerebral palsied children. The point that I make in this chapter is that the studies involving cerebral palsied children overemphasize perception as the basis for later cognitive development. The idea that perception is the prerequisite to cognitive ability is not true. The results of developmental studies have shown that the intellectual disorders found in cerebral palsied children should not be attributed to their perceptual deficiencies but to their lack of experience with the physical world.

In Chapter 2, I describe the current educational methods used to teach cerebral palsied children. The ideas that emerge from these methods are that perceptual deficits are viewed as contributing to inadequate cognitive performance and must be corrected before academic achievement can occur. The educational emphasis has been on determining what aspects of a child's perceptual functioning are deficient so they can be remediated. The alternative that I propose is that rather than dealing with the perceptual deficits per se we should take a more cognitive approach to education. This means that (a) it is important to consider what happens to the mental structure of the person who is learning and to view learning as constructing, (b) it is the learner who should be in control in the teaching-learning situation, not materials, lessons, teachers, or other factors external to the learner, (c) the role of education is to provide activities to facilitate the learner's ability to construct meaning from experience, (d) it is vital for the learner to understand that he or she must be active in his or her own learning, and (e) learning is a process of elaborating what the

child already knows, rather than a process of accumulating bits of information and skills.

In Chapter 3, I describe the research proposal and the methodology adopted in the research. The research proposal is that the computer can be an effective assessment and learning tools to be used with the physically handicapped. To demonstrate this I develop two studies: the screen task study, and the indepth study of children using Logo. The objectives of the screen study are: (a) to develop a computer system to implement performance tasks, so physically impaired children can manipulate objects with minimal effort; (b) to implement the seriation task in this system; (c) to investigate whether severe motoricly impaired children can benefit from the computer system to help them manipulate "objects" on the screen, thus making possible to assess their intellectual development with performance tasks, rather than multiple-choice tasks; (d) to investigate whether the development of the capacity to seriate can reach, after a certain age, a stage of stability, as in the case of normal children; (e) to explore whether physically handicapped children are able to succeed in the seriation task, regardless of their degree of motor impairment; and (f) to study whether physically handicapped children approach the seriation task by adopting strategies that are similar to the ones adopted by normal children.

The objectives of the indepth study are: (a) to make the Logo environment available to several cerebral palsied children; (b) to investigate whether the computer can be used to increase the intellectual potential of these children; (c) to analyze the specific pathways to improvement, in particular to distinguish between having knowledge, being able to access the knowledge, and becoming more critical about one's own performance; (d) to dissect as far as possible the specific contributions of the use of the computer; and (e) to understand general aspects of the learning process.

In Chapter 4 the seriation experiment, designed by Jean Piaget, is described in terms of what it tells us about a child's knowledge, how it has been implemented on a computer, and how cerebral palsied children performed in this task. The results are used to demonstrate that at least part of these children's failure to seriate appears to be related to a lack of performative knowledge, such

as developing, carrying out, and debugging a plan of action, rather than a lack of concepts involved in the task.

Chapters 5, 6, and 7 are case studies of the cerebral palsied subjects who participated in the project. These case studies illustrate, in rich detail, themes presented in previous chapters. They are presented as models of human interaction in a programming environment, emphasizing the transitions in these children's computer activities and the incidents that made these transitions possible. In Chapter 5, I describe Mike's work. He is the student who has spent the most time in the project and who has benefited the most from the computer activity. Some of the findings from his work have already been mentioned in this Introduction.

In Chapter 6, I describe James' computer activities. James was selected to participate in the project because we decided to work with subjects who had severe motor disabilities and were younger than Mike. James was 14 years old when he started working with Logo. He is a quadriplegic spastic cerebral palsied. He has sufficient motor control in his right upper limb to work his wheel chair, feed himself, type and write, although the latter he does very slowly and poorly. In his initial contact with the computer it was possible to observe a series of idiosyncrasies that made James quite different from other cerebral palsied subjects I had seen. For example, among the few cerebral palsied children who were asked to experiment with the computer seriation task he was the only one who could not seriate the real sticks but was able to seriate the sticks on the computer screen. James' computer activities, which consisted of turtle drawings and of producing a weekly newspaper by using the computer text-editor, demonstrated that his writing skills were much superior than to his abilities to use the Logo commands to produce geometrical drawings. In the description of James' computer work I show how remedial computer activities helped him to develop some of the concepts necessary for his drawing activities. This supports the hypothesis that cerebral palsied children's intellectual deficiencies are not directly due to brain lesion.

In Chapter 7, I describe Kate's computer work. She was a 13-years-old girl when she was

involved in the project, with an overall intellectual disability. She is quite friendly, very verbally alert, and eager to work with people. She is a quadriplegic spastic cerebral palsied, more severely in her lower limbs. Besides her physical handicap Kate's cognitive skills are very limited. On the seriation task she was unable to achieve even partial seriation, which is ordinarily expected of a 5-years-old. On her turtle geometry activities she demonstrated problems similar to those experienced by James. She had a strong tendency to use sequential numbers as the inputs of Logo commands, and had difficulty commanding the turtle to a particular place on the screen. The remedial program I set up for Kate was to help her to become more independent and to learn how to control her own activities. This process took a long time, although by the end of the project she was able to analyze problems and adopt appropriate solutions. She showed her mastery when she solved the seriation task for the second time, shortly before the end of the project. She was able to do the computer version of the seriation task. Before she started to arrange the sticks she spontaneously named each stick according to their size (longest, second longest, etc.) and then used this information to help her to select the sticks.

Chapter 8 provides a summary of results of the studies described in the thesis.

In Chapter 9 I integrate the themes of the thesis and the results from the thesis into a form which allows us to look at and evaluate the construction of learning environments. In addition, I provide some pedagogical principles which I can identify, in retrospect, as essential in guiding me through my work. While these principles came directly out of my work with cerebral palsied children, I feel that they are appliable to the development of any learning environment.

Chapter 1

Cerebral Palsy : Physical and Intellectual Disorders

In this chapter I discuss the physical and intellectual disorders afflicting cerebral palsied children. The objective is to understand the nature of these disorders in order to design effective learning environments to help these children to overcome their disabilities. I review the cerebral palsy literature and I show that cerebral palsied children, compared to nonhandicapped children, have a lower average IQ. These intellectual deficiencies are attributed, by some professionals in the field, to these children's poor perceptual skills. These authors have assumed that the development of higher-level functions is dependent upon acquisition of lower-level processes such as perception. Based upon this view, perceptual studies have shown that cerebral palsied children have attentional deficiencies (characterized by forced responsiveness, perseveration, and distractability) and perceptual-motor deficiencies (characterized by an inability to interpret stimuli and to manipulate objects under visual control), which must be corrected before academic achievement can occur. However, the idea that perception is the basis of adequate conceptual ability receives little support from either current cognitive-developmental theorists or from information-processing theorists. The few cognitive studies conducted with cerebral palsied children have shown that disorders in certain cognitive functions are of developmental nature -- a delay rather than a developmental deviation.[1] *These results can have a major impact on the educational and life-enhancing approaches that are used with cerebral palsied children.*

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1. The term developmental delay is used to indicate an intellectual development that follows the same pattern as in the case of normal individuals but occurs much later.

1.1 What Is Cerebral Palsy

Cerebral palsy is characterized by an inability to fully control motor functions. It is a condition caused by damage to the brain, usually occurring before, during, or shortly following birth. It is neither progressive nor communicable. Neither it is "curable" in the accepted sense, although it is often amenable to training and therapies.

The question of the timing of the brain lesion is of great relevance to the understanding of cerebral palsy. What distinguishes cerebral palsy from other forms of physical handicaps, such as poliomyelitis, is that in cerebral palsy the physical impairment is due to brain lesions that occur during the period that the nervous system is most vulnerable -- before its functional integrity is fully established. Neurological studies show that brain damage sustained during this period is more diffuse and produces more pervasive behavior problems than damage to the mature brain (Issacson, 1975; Rosner, 1974). Thus, in addition to the motor dysfunction, cerebral palsied individuals may suffer from a large spectrum of intellectual disabilities -- perceptual and cognitive -- depending upon the location, severity, and extent of the neurological damage.

It is estimated that some 700,000 children and adults in the U.S., -- about 16 out of every 5,000 people -- have cerebral palsy. Approximately 10,000 infants are born with this condition each year and some 2,000 young children acquire cerebral palsy as a result of head injuries. Although measures of prevention are increasingly possible, there is no way of totally eliminating the causes of cerebral palsy since any damage to the brain, whether caused by defective development, injury or disease, may produce this condition. Chief among the causes is an insufficient amount of oxygen reaching the fetal or newborn brain. This oxygen interruption, in turn, can be caused by premature separation of the placenta from the wall of the uterus, an awkward birth position, labor that goes on for too long or is too abrupt, or interference with the umbilical cord. [1]

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1. Less common causes today are premature birth, infection of the mother with virus diseases in early pregnancy, viruses or bacteria which attack the newborn's central nervous system, and head injury resulting from accident or child abuse.

1.2 Physical Disorders in Cerebral Palsy

A great effort has been made by clinicians and researchers to classify all cases of cerebral palsy. The most common categories are based upon clinical characterization of cerebral palsy, location of motor dysfunction, and degree of severity of motor disabilities.

The four most common clinical characterization of cerebral palsy are: (a) Spastic, characterized by tense, contracted muscles and exaggerated reflexes. It is the most common form of cerebral palsy with approximately 50 to 60 percent of the cerebral palsied population classified as spastic; (b) Athetoid, characterized by uncontrollable, jerky, irregular movements of arms and legs. Approximately 20 to 30 percent have this type of cerebral palsy; (c) Ataxic, characterized by poor sense of balance and posture. This is a less frequently found motor disorder among the cerebral palsied. Only 1 to 10 percent are ataxic; (d) Mixed, characterized by combinations of the above types of disordered movement. Athetosis combined with spasticity, or with ataxia, is frequently encountered. Approximately 30 percent have mixed types of cerebral palsy.

Classification based upon location of the motor dysfunction complements clinical classification. The various sites of motor disabilities are: hemiplegia, involving both limbs of the same side of the body; quadriplegia, all four limbs are impaired; diplegia, involving both upper limbs or both lower limbs (called parapiegia); and monoplegia (one limb) and triplegia (three limbs) which occur very rarely.

The degree of involvement is classified as: mild, characterized by impairment of fine precision movements; moderate, characterized by impairment of gross and fine movements, but with functional performance in the usual activities of living; and severe, characterized by inability to adequately perform usual activities of daily living such as walking, dressing, washing, and feeding.

Although these classifications place great emphasis on the impairment of limbs, it is important to mention that movements of other parts of the body are affected as well: movement of the eye,

jaw, tongue, head, facial muscles (related to facial expression), etc. Nearly one-third of cerebral palsied children have visual defects of refraction and muscle control; 20 to 25 percent have hearing disabilities; and 70 percent have speech impairments.

As consequence of their overall motor dysfunctions, cerebral palsied individuals have great difficulty interacting with the physical environment and with people around them. In general, they cannot move by themselves, and they have difficulty in handling objects. They have difficulty carrying on communication with other people, and have a tendency to assume a passive role when interacting with people or manipulating objects. It is assumed that this lack of interaction, independence, and activity, combined with the presence of brain lesions, are the causes of the intellectual deficiencies found in the cerebral palsied. This has been the main concern of parents, teachers, therapists, and clinicians.

1.3 Intellectual Deficiencies in Cerebral Palsy

Cerebral palsied individuals are known to have a hard-to-define intellectual retardation which, in general, does not always have the characteristic effect of later brain injury. For example, they do not present some of the intellectual dysfunctions that are found in patients with aphasia[1] who have suffered brain lesions later in life.[2] Several studies, however, have shown perceptual and cognitive deficiencies in cerebral palsy, and some authors have often referred to cerebral palsy as a disorder of spatial perception (Abercrombie, 1964; Cruickshank, 1976a). In this section I present some findings about intelligence, perception, and cognition in cerebral palsy so we can

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1. Aphasia is defined as a defect or loss of language function, in which the comprehension or expression of words (or nonverbal equivalents of words) is impaired as a result of injury of the central nervous system. Woods and Carey (1979) showed that left hemisphere lesions, if incurred before one year of age, do not result in significant impairment in a variety of language tasks, but left hemisphere lesions after one year, if they cause initial aphasia, leave significant residual impairment on most of the same language tasks.

2. The only cases of aphasic cerebral palsied mentioned in the literature are children having kernicterus as the cause of cerebral palsy (Cohen and Hannigan, 1956; Cohen, 1956; and Hannigan, 1956). Kernicterus is the result of Rh (Rhesus) incombatibility between mother and child, other blood factor incompatibility or other conditions in which jaundice occurs in the neonatal period. These conditions can be diagnosed and elliminated by medical procedures. Today they are very rare cause of cerebral palsy.

understand the nature of these deficiencies and explore whether they can be overcome by providing these children with the experience they lack in their lives.

1.3.1 Intelligence in Cerebral Palsy

It was not until the 1950s that researchers were able to evaluate rather clearly the level of intelligence in cerebral palsied individuals. The results of the 1951 New Jersey Survey of 1,000 cerebral palsied children (Cruickshank, Hallahan, and Bice, 1976b) showed that the average IQ score, as measured by the Binet intelligence test, was 68. Approximately 48 percent of the total group had IQs below 70, and 28 percent had IQs above 90. Similar results were found in other studies: Miller and Rosenfeld (1952); Floyer (1955); Ingram (1955); Cockburn (1961); and Rutter, Grahan, and Yule (1970).

There are two facts that emerge from these findings. First, cerebral palsied children have an average lower IQ than nonhandicapped children. Among the nonhandicapped children only 2 per cent have IQs below 70 and the average IQ is approximately 104 (McNemar, 1942). Second, about 28 to 35 percent of cerebral palsy children are not intellectually impaired. This suggests that in relation to general intelligence the cerebral palsied are a fairly heterogeneous group; that is, mental deficiency may occur more frequently than among the normal population because cerebral palsy tends to be associated with damage to, or maldevelopment of, parts of the brain other than the motor cortex (Stephen and Hawks, 1974).

Although these studies indicate that cerebral palsied individuals have a low level of intelligence, these results have to be interpreted with some caution. They may be unreliable and misleading. First, we know that, in addition to their physical handicap, many cerebral palsied children suffer from associated complications such as impaired vision or speech. Thus, we can argue that when a multi-handicapped child is presented with an ordinary intelligence test, it is difficult to judge her fairly. Perhaps the child is unable to apprehend the test material correctly because of sensorial impairment, or her response may be inhibited by motor handicaps or speech disorders. Second, as Yates (1966) has pointed out, brain lesions can produce, in addition to a general deterioration

in all aspects of intelligence, both differential and specific effects depending upon location and extent of lesion. Thus, it is quite possible that these tasks may be assessing other differential or specific disorders of these children. For example, the New Jersey study shows that cerebral palsied subjects had a high percentage of success on the verbal subtests, and a low percentage on the subtests that require visuo-motor or constructional skills -- often referred to as "performance" tasks, such as copying a figure, and paper folding. These tasks involve spatial relationships of objects or parts of objects which the child has to *visually perceive* in order to motoricly ***execute*** a response. Thus, the cerebral palsied children's low IQ may be due to their inability to either process what they see or to execute what they want.

This higher proportion of mentally defective children, compared to nonhandicapped children, and the disparity between test results in verbal and performance tasks, has led researchers to investigate whether cerebral palsied children have specific intellectual dysfunctions, producing a "standard" group of behavioral symptoms. The area that has received the greatest attention is the study of perception. As Allen (1962) has put it, for the psychologists, "the role of perception in the functioning of the cerebral palsied is almost the entire story of cerebral palsy as a condition" (cited in Diller and Birch, 1964, p. 28).

1.3.2 Perceptual Disorders

Most of the studies of perception in cerebral palsied children are based upon Werner and Strauss's experimental work with brain-injured children (Werner and Strauss, 1941; Strauss and Werner, 1942). Werner, one of the foremost theoreticians of child development and comparative psychology of his era, was particularly intrigued by the relationship between perceptual and conceptual development in children. Both authors have posited a model of child development in which early perceptual-motor activities were crucial to conceptual development (Hallahan and Cruickshank, 1973). Since perception was viewed as the basis for later cognitive development, methods of determining aspects of a child's perceptual functioning were developed. Perception was consequently viewed as an entity which could be subdivided into

component parts for both assessment and subsequent remediation. Components such as figure-background perception, auditory perception, spatial relations, and position in space were identified as discrete elements. [1] The literature on perception in cerebral palsy indicates that cerebral palsied individuals have perceptual disorders involving all the sensorial modalities, such as visual, tactile kinaesthetic, auditory, and percept of bodily position (Abercrombie, 1964). In this section I discuss only the visual aspect of cerebral palsied children's perceptual disorder because the computer activities are closely related to the psychological tests used in these studies. The points I want to make are that cerebral palsied children's visuo-perceptual (perception through vision) as well visuo-motor (manipulation of objects under visual control) disorders should not be regarded as directly related to impairment of motor abilities, nor should they be related to an inability to perceive in the sense of being aware of a stimulus. Since children who exhibit poor performance in these tests may have no visual disorders as defined in an ophthalmological examination the disorders should not be related to a visual deficiency either. This means that difficulty in manipulating objects, walking, attending, and seeing is not sufficient to explain the poor perceptual performance of these children.

Visuo-motor tests require the child to perceive a situation and produce a response that involves manipulation of objects under visual control, such as drawing or constructing patterns with marbles, sticks, bricks, etc. Thus, it has been argued that the difficulty cerebral palsied children may have in these tests can be attributed to their lack of motor coordination. Their failure to put two red and two white bricks together to match a model may be directly related to their inability to manipulate objects. The evidence for this was presented by Bortner and Birch (1962). They administered the block-design test[2] to 28 cerebral palsied children. Each child was asked to

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1. In order to distinguish the notions of perception as the basis of cognition, and perception as part of cognition, henceforth I will denoted the former with roman font (perception), and the latter with italics font (*perception*).

2. Block-design test is a subtest of Wechsler Intelligence Scale for Children and consists of putting colored blocks together so that the top surfaces make a colored pattern to match a diagram.

reproduce a block-design. After the subject had failed three consecutive designs, the experimenter presented the child with the stimulus card, together with three block designs: one an accurate copy, the child's own incorrect solution, and another incorrect solution. The child was asked to indicate which one looked like the design on the card. The results showed that the group as a whole failed to reproduce a total of 89 designs. Of the 89 failed designs, 70 were correctly discriminated by the subjects in choice situation. This indicated that the ability to discriminate was intact in four-fifths of cases even though ability to reproduce the same designs was impaired. This finding has been confirmed by other investigators. Simpson's studies (1967, and 1974) showed that cerebral palsied children tended to do better on discrimination tasks than on drawing tasks, and Zeitchel and his co-workers (1979) have shown that measures of perception in cerebral palsied children yield scores progressively lower as the motor components of the test increase.

However, other studies with cerebral palsied children have produced results that indicate that the difficulty in visuo-motor tests cannot be attributed entirely to motor dysfunction. It is important to remember that these tests, in addition to motor response, also involve the ability to *visually perceive* relationships that may be essential to perform the task. The question of whether motor handicap, in itself, accounts for the major difficulty in visuo-motor tests was studied by Abercrombie and her co-workers (1964). They used the performance subtest of Wechsler Intelligence Scale for Children (WISC)[1] with two groups of children: one consisted of cerebral palsied children; and the other, a control group, formed by children who presented no clinical signs of brain damage but had suffered from the time of birth, or within their first three years, the same limitations of bodily movements as occur in cerebral palsy. They found that the performance score of the control group was within normal range (mean equal to 95), but the cerebral palsied group was considerably lower (mean equal to 66), and concluded that

1. The WISC test separates intellectual assessment into verbal and performance abilities. The verbal subtests of the WISC are: information, comprehension, arithmetic, similarities, vocabulary, and digit span; the performance subtests are: picture completion, picture arrangement, block design, object assembly, coding, and mazes.

"difficulties of manipulation, and limitation of spatial experience due to restricted locomotion, do not necessarily result in specific disability in the WISC Performance Scale"(op. cit. p. 576). A similar result was found in the study that I conducted with 32 severe cerebral palsied children, described in Chapter 4. These children performed two versions of the seriation task:[1] the standard version of the task, using wooden sticks, is the same method as described by Piaget (1965); and the computer version, in which the computer was used to move sticks, represented as lines on the computer screen. Although the computer was introduced to minimize the motor effort necessary to perform the task, only three children who could not do the standard version of the task were able to seriate using the computer. In addition, the results showed that there was no correlation between ability to seriate and degree of motor impairment. These studies demonstrate that the intellectual disabilities in cerebral palsied children are not entirely caused by lack of motor experience. However, this does address the combined effect of lack of motor experience and brain damage.

Since the intellectual disorders cerebral palsied children have cannot be attributed solely to their visuo-motor deficiencies, several studies have been conducted to investigate whether the deficiencies are of perceptual nature. These studies have used visuo-perceptual tests in which the child is asked to indicate, usually by verbal response or pointing, that things appear to him either alike or dissimilar. For example, an object (the test item) may be presented to the child who has to find among several others (multiple-choice items), one that is similar.

Visuo-perceptual studies with cerebral palsied children were based upon Werner and Strauss's experimental work which showed that brain-injured children had a significantly poorer

1. The seriation task consists of presenting a cluster of randomly oriented "sticks" of different sizes, and asking the child to arrange them in serial order along a horizontal line representing a table top.

performance than both normal and mentally retarded children on the figure-background tests[2] (Werner and Strauss, 1941). They selected this aspect of perception because (a) in Gestalt psychology the ability to discriminate figure from the background was thought to be one of the fundamental and most primitive activities of the organism, and (b) in Goldstein's work with brain-damaged adult, he had extended figure-ground relationships beyond perception into a basic principle of neural organization, so that what held true for perception held true also for thinking and memory (Diller and Birch, 1964).

Dolphin and Cruickshank (1951a) replicated the figure-background experiments with two groups of children matched for chronological age, mental age, and IQ level. One group formed by 30 cerebral palsied children (mean chronological age, 10.03 years, mean mental age, 9.5 years, and mean IQ, 93.5); and the other formed by 30 physically normal children. Their results were quite similar to those documented by Werner and Strauss. The cerebral palsied children did less well than did the nonhandicapped children in both versions of the background test.[3] Cerebral palsied children were distracted by the background, which constantly interfered with discrimination between the figure and the background. The authors suggested that this was due to forced responsiveness to extraneous stimuli, or to meticulosity which made the child include reference to background. Similar results were found by Cobrinik (1959). In his study cerebral palsied and normal children were required to find hidden figures from their masked context. He observed that the two groups of children performed equally well on the simpler items; however,

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2. The figure-background tests consist of presenting a picture of common objects or geometrical shapes drawn on a patterned background consisting of jagged and wavy lines, or dots, or overlapping figures. The subject is asked to either match a figure to a concept, ignoring the background, or identify a hidden figure.

3. One version of the test was called the picture test. Drawings of common objects -- a hat, a milk bottle -- embedded in clearly structured background were tachistoscopically exposed for 1/5 second, twice in succession, and the child had to tell what she had seen. In the other test, called the multiple choice test, a geometric figure of heavy dots embedded in small dots was presented for 1/2 second. The child was then shown three cards: original background only, original background with different figure, and original figure with different background. The child was asked to pick the one most like the previously seen.

as the items became more difficult, cerebral palsied children performed less well. He also noticed that the degree of difficulty in the hidden figure task was related to the severity of the motor handicap, and concluded that hidden-figure deficit was more a matter of the extent of cerebral damage than of location of lesion.

These findings can be criticized on several grounds. First, any notion of simple causality between brain lesion and behavior is incomplete and misleading. This criticism can be applied not only to the figure-background studies, but equally to most of the studies involving children with brain damage. This view suggests that the behavior observed, which leads the child to failure in the task, may have developed in the course of atypical relations with the environment as opposed to a direct consequence of brain lesion. By their hopeless inability to achieve what they so much want to do, the children may get upset, lose track of the problem to be solved, and persist in a particular solution without being able to retract. Second, it is important to keep in mind that the figure-background studies were motivated by the idea that perception is the ability to register sensorial information. This view has proved to be too simplistic. Today *perception* is best viewed as a process of information extraction or information processing (Anderson, 1980). It is believed that *perception* involves the analysis of relations, sequences, classes, categories, objects, and symbol systems. It is not considered a passive reception of stimuli, but rather a processing of information by higher-level systems such as those of memory, reasoning, attention, problem solving, and language. Based upon this new understanding of *perception* it is quite possible that cerebral palsied children's difficulty with the figure-background task may be due to the fact that these children, in order to cope with their environment, have learned to pay attention to the background more than normal children. The cerebral palsied may have learned to respond to the larger patterns -- the background, rather than the figure. Indeed, Nelson (1962) found that stimuli were used differently by cerebral palsied children when performing visual discrimination tasks. His subjects judged geometrical figures on the basis of solid figure rather than the contour -- the capacity to analyze figure outline was poorer than the capacity to analyze solid figure. This finding suggests that cerebral palsied children may have difficulty in unscrambling figures from

background because their response is based on a different set of cues. This has been confirmed by Birch and Lefford (1964). These researchers found that visuo-perceptual deficiencies in cerebral palsied children were due to their poor ability to analyze and synthesize visual stimuli. They showed that there was a statistically significant difference in performance between cerebral palsied and non-physically-handicapped normal children in three tests: visuo-perceptual discrimination (discriminate visually among a set of 12 geometric forms), analysis (find in a whole figure isolated parts of the figure), and synthesis (select one of four sets of lines which could be used to construct a whole figure). The easiest test for the cerebral palsied group was the discrimination test, and the hardest was the synthesis test. Birch and Lefford concluded that analytical and synthetic disabilities in cerebral palsy are result of a poor capacity to integrate or organize information in meaningful ways.

Thus, the poor performance of cerebral palsied children in visuo-motor and visuo-perceptual tasks should not be seen as an inability to register information but as deficiencies in their capacity to process information. This implies that, instead of looking at their perceptual abilities as the source of their poor performance in the intelligence tests, we should analyze their cognitive functions, their abilities to know and to learn. By proposing this change in the way we see the intellectual deficiencies in cerebral palsied children, I am assuming that perception and cognition do not form a developmental hierarchy but that the way we *perceive* the world depends upon our ability to learn and to think in a continuous and interactive fashion.

1.3.3 Cognitive Disorders

Since the traditional research approach has emphasized perception as a prerequisite for intelligence, there are relatively few studies on the cognitive development of cerebral palsied children.

One of the first researchers to investigate cognitive capacities in cerebral palsied children was Cotton (1941). She used a series of sorting or concept formation tests to study a group of severely handicapped but presumably normally intelligent spastic children, aged 7 - 13 years, matched for

sex, age, and mental age, with a group of nonhandicapped children. The results showed that the spastic children had a far greater tendency to form unusual relationships between the various objects in the sorting test than did the controls. Considerably more spastics than normal subjects showed signs of perseveration and rigidity, finding difficulty in changing from one sorting principle to another.

Dolphin and Cruickshank (1951b) also studied concept formation in cerebral palsied children and nonhandicapped children, matched for age and IQ level. The subjects had to select among many objects "those objects which go with the picture" (p. 28). They found the same qualitative and quantitative differences between these two groups of children as had been found by Cotton. The cerebral palsied children selected a significantly greater number of objects than did the normal children, and their choices included a greater proportion of "unusual" objects, ones with no apparent relation to the picture. The cerebral palsied children's justification for their choices were based on less important and less characteristic properties of the objects.

In order to understand the reasons for impairment in the development of concept formation in cerebral palsied children, Melcer (1966) designed a series of experiments to investigate the relation between sensory-motor experience and the formation of concepts of object and action in childhood -- the development of a mental representation for a class of objects and events. His research is based on the assumption that there is a qualitative difference between object and action concepts in the early stage of children's intellectual development and that the latter is influenced by sensory-motor experience. To study the validity of Melcer's hypothesis, two groups of children were compared for number and type of acquired concepts. One group was formed by cerebral palsied children, and the other was formed by normal nonhandicapped children. The age range of children tested was approximately 42 to 66 months. Melcer observed that cerebral palsied children do not develop action concepts in the same ratio to object concepts as do children who are not motoricly impaired. Cerebral palsied children tend to get what they want in means-ends situations by activity modes that involve less overt motoric action than

nonhandicapped children.

Melcer's assumptions are based on Piaget's theory (1977) which postulates that sensory-motor activities are the source from which mental operations emerge.[1] Thus, children with limited capacity to interact with the environment, due to sensorial or motoric disabilities, should have impaired intellectual development. This hypothesis has been confirmed through a series of studies with sensorial and motoricly deprived children. Furth (1971) worked with congenitally deaf children and showed a generalized but minor lag in the intellectual development of these children. Hatwell's research with congenitally blind children (1966) compared their performance to sighted children in the areas of spatial notion (displacement and rotation of objects); physical operations (conservation of substance, volume, and weight); logical operations (classification and seriation); and verbal logic (class inclusion). She found long delays in the development of most concrete operations, presumably related to these children's lack of visual input and consequent restricted mobility. Not surprisingly, the longest developmental delay was for concepts related to space and physical logic (4-6 years) and the least affected area was verbal logic (0-2 years). Decarie (1968) studied the development of the object concept in thalidomide children aged 18 to 41 months and has found that there is a delay of 0-7 months, compared to normal children, in the accession to the final stage of object concept.

These findings have several implications to an understanding of cerebral palsy and how we should deal with cerebral palsied children. First, they indicate that, in addition to neurological factors, sensory-motor experience is also a major factor in the development of certain aspects of

1. According to Piaget's theory the child's intellectual development progresses through stages which build on knowledge acquired in previous stages. The sensory-motor period is the first stage and is the basis of all later development. He stated that during the sensory-motor period (first two years of life) the child modifies automatic patterns of behavior into more complex and more truly intelligent behavior. For example, the sucking structure becomes more elaborated and develops into a more complex structure which then incorporates the results of the infant's experiences. Children start sucking their hands, and later sucking is combined with grasping and visual structures to encompass sucking of objects that are seen and grasped. At this level, learning can be said to be the creation of structures which connect and coordinate reflexes which previously operated in "ignorance" of each other.

these children's intellectual abilities. Second, they suggest that we should set up a different agenda for the research we conduct with handicapped children. The main concern should not be the perceptual-motor deficits these children have, but rather we should be concerned with the combination of brain lesion and lack of sensory-motor experience on the development of cognitive functions. It seems that, up to now, the task of uncovering a perceptual or motor disturbance has absolved researchers from the responsibility of accounting for this disturbance or developing methods to address it. By just describing the behavioral problems of a cerebral palsied child as "perceptual" or "motor" we may be substituting one label for another. Third, if their cognitive disorder is dependent upon impaired sensory-motor experience, the development of cognitive functions in cerebral palsied children should benefit from educational programs designed to provide them with the means to interact more with their environment. This is a central theme of this thesis. I will discuss educational issues related to this theme in the next chapter. For the moment I would like to explore the question of whether the literature presents any evidence that cerebral palsied children's intellectual deficiencies can improve as these children become more experienced in interacting with their environment. In other words, I want to know whether these children's intellectual behavior can be attributed to a developmental delay, or whether it is something qualitatively different from the development observed at corresponding stages in normal children.

1.4 Developmental Delay or Deviation?

Melcer's results allowed us to conclude that the intellectual behavior observed in cerebral palsied children can be attributed to a combination of brain lesion and lack of experience. However, the question of whether these children can benefit from an educational program that provides them with the experience they lack cannot be inferred from Melcer's results. It is quite possible that the effects of neurological impairment to the developing brain is irrevocable, producing an intellectual development different from the development of normal children. On the other hand, it is quite possible that the bizarre intellectual behavior we observe in cerebral palsied children is the result of a primitive or immature cognitive structure which can be enhanced by specially

contrived environmental conditions. As Abercrombie (1964) has observed, "This is by no means only an academic exercise on the ever-fascinating 'nature-nurture' controversy, but has very important implications for the practical management of handicapped children" (p. 17).

The results of developmental studies have shown that intellectual disorders in cerebral palsy are not static. However, the difficulties in making any valid generalizations about these results should not be underestimated. For example, there are several problems in matching cerebral palsied and normal children with regard to childhood experience, and in finding appropriate tests that are sensitive to the condition of physical impairment. As Teuber and Rudel (1962) observed, brain-injured people may or may not differ from normals of the same age, depending on the kind of test used and the age at which it is administrated, and brain-injured adults may or may not resemble normal children, depending on the test used.

In a controversial paper, Nelson (1962) found that in spastic cerebral palsied children there was no correlation between chronological age and score on visuo-perceptual tests, but there was a high correlation between chronological age and visuo-motor tests. The same tests repeated with normal and nonhandicapped retarded children showed exactly the opposite results. This he says, "clearly suggests that we are dealing with a developmental bifurcation" (op. cit. p. 326). Nelson indicates that the perceptual difficulties of the spastic result from neurophysiological impairment associated with the optic pathway. This may be further complicated by maturational factors, such as demonstrated by a comparison of normal and mentally defective children. He found that when groups of children were equated for chronological age, normals did better than mental defectives, but when groups were equated for mental age, mental defectives did better than normals on visual tasks demanding perception of borders. According to Nelson, the visual difficulties of spastics are due both to specific brain pathology and maturational delay.

The problem of interpreting Nelson's findings is that his research is based on several variations of only one type of task. To the extent to which these results can be generalized is unknown. It could be the case that in this particular situation the tasks demanded perception skills that spastic

children could not make, although, as a group, the cerebral palsied children were not intellectually backward when compared to normals and to mental retarded children.

The majority of the developmental studies seem to indicate that cerebral palsied children are intellectually underdeveloped. Floyer (1955) studied 72 cerebral palsied children, 36 boys, and 36 girls, matched with normal children for sex, chronological age (between 6.6 and 15.11 years), and IQ level (none below mental age 6.6 years). She found that there was evidence for greater visuo-motor handicaps among the younger boys than the entire age range. She suggested that the handicap in cerebral palsied children might better be considered a developmental lag with some continuing weakness than as a disturbance. A similar conclusion was reached by Nielsen (1962) and Wendell (1960). These authors reported that visuo-motor retardation was most marked in younger children. Wendell (1960) suggested that the improvement might be due to the accumulation of limited sensory-motor experience and to the gradual unraveling of confused kinaesthetic and other sensations.

Studies of cognitive abilities in cerebral palsied children have also shown evidence of developmental delay. Sternlieb (1977) studied 45 motoricly healthy and 45 cerebral palsied children divided equally into three age groups (5-6 years, 8-9 years and 11-12 years), using three Piagetian tasks: stereognosis, localization of topographical positions, and class inclusion. His results showed a delayed developmental progress for cerebral palsied children. The control group had significant progress between the ages 5-6 and 8-9, but nonsignificant improvement between the ages 8-9 and 11-12; cerebral palsied children demonstrated no significant improvement between the ages 5-6 and 8-9, but showed significant developmental progress between the 8-9 and 11-12. He concluded that there is a 2-3 years lag in cerebral palsied children's ability to perform these tasks, compared to normal children, although there is a significant developmental progress in these children's abilities to perform these tasks between the ages 8-9 and 11-12 years. He attributed this developmental delay to the lack of sensory-motor experience and suggested that

> It is possible that cerebral palsy children spend more time organizing sensory and motor schemes than normal children. Instead of the typical two years (approximately), they may take as long as 4-5 years in order to be able to crawl or walk around, even with the aid of crutches, braces, or a walker. (op. cit, p. 66)

Although these studies indicated that intellectual development in cerebral palsied children is delayed, rather than distorted, these findings should not be seen as a guarantee that all cerebral palsied children will be able to catch up with the development of normal children. Follow-up studies have shown that severely defective cerebral palsied individuals remained defective, even after 14 years (Klapper and Birch, 1967). These authors found a higher proportion of normal IQ scores among their cerebral palsied subjects than were obtained at initial testing. However, the great change in the direction of improvement occurred in those children whose initial IQ placed them in the mildly subnormal or borderline normal range. Similar results were obtained by Cronholm and Schalling (1968). A group of adult cerebral palsied individuals was examined with a test battery and compared with a control group. They found relatively small differences between cerebral palsied subjects and controls with regard to verbal, memory, concept formation, and sorting. However, specific perceptual defects, characteristic of cerebral palsied children, were found in the cerebral palsied adults.

To summarize this chapter, it seems that, as far as intellectual development is concerned, the evidence indicates that cerebral palsied children can be better described as suffering from a cognitive developmental lag, although the degree of disability varies according to location, severity and timing of brain lesion, and environmental experiences. These children's deficits in performance may represent not simply an inherent handicap, but an absence of learning experiences. Thus, the fact that the intellectual disorders in cerebral palsy may be of a developmental nature creates the possibility of overcoming them through educational programs whose main objectives should be to provide these children with the experience they lack in their lives. Unfortunately the processes of education and training of children with cerebral palsy has been based on a narrow view of the problems these children have. These issues are discussed in the next chapter.

Chapter 2

Education of Cerebral Palsied Children

Two types of remedial education have been the predominant methods used to teach severe cerebral palsied children: task-analysis and diagnostic-remediation. In this chapter I will discuss both methods and demonstrate that they are both integral aspects of the techniques used in the Logo environment. The objectives of using these methods in Logo, however, is very different from the goals reported in the cerebral palsy literature. The approach in Logo is to remove from the educator's total control the determination of which skill to teach the child, or which diagnostic tool to use to evaluate the child's psychological and educational capacities. In the Logo environment we provide the conditions in which children can be evaluated according to their interests and commitments. Also, we want the child to tell the educator which skills need remediation, instead of the reverse. It is our conviction that only such an educational approach will truly evaluate children's potential and provide the experience required for the physically handicapped to compensate for their limited interaction with the physical world. This creates a need for remedial programs in which children have more control over the activities they perform and have a chance to express their intellectual abilities.

2.1 Education Methods to Teach Cerebral Palsied Children

To date, there has been little agreement among educators and researchers about which educational method is the most appropriate to be used with children with cerebral palsy. In the literature on this subject, several points emerge. First, an educational program for cerebral palsied children must encompass more than just the provision of academic skills. As Cruickshank

(1976a) has pointed out, an affective educational program has to meet the several distinct needs of these children, including different intellectual, physical and learning deficiencies. Second, common sense is stressed. Since cerebral palsied children have different personal needs, and may require unique and individual educational attention, it is difficult to generalize. This has demanded a great deal of improvisation from educators, and the adaptation of teaching materials, activities, and evaluation techniques. This has also contributed to a large number of variations in teaching methods, which have not been reported in the literature.[1] Third, education methods are based on an additive model, which focuses on observable, repeatable, and countable behaviors and events. This view assumes that learning occurs as the result of presenting bits of information that are hierarchically sequenced so that those taught first can be integrated into more complex behaviors. Accordingly, if the child evidences problems in reading, it is assumed that there must be difficulty with more fundamental abilities, such as visual discrimination or visual perception. These underlying abilities, then, become the focus of the educational activities. Instruction begins with small bits of information, thought to be the easiest; as they are mastered, other easy bits are introduced, and then more difficult ones. If the child does not produce the desired response, practice is continued.

There are several educational methods (or variations of these methods) that have been used with cerebral palsied children. The selection of a particular method depends upon several factors, such as the child's degree of physical and intellectual impairment, the activity or knowledge domain in consideration, and the educator's philosophy regarding the nature of education. For example, Calhoun and Hawisher (1979) recommend that for cerebral palsied children who have demonstrated a reasonable acceptance of their handicap and can compensate adequately for the limitations imposed by their disability, a regular school classroom provides the best educational situation. If these children require supportive therapy (speech or physical), this can be done in the

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1. During my visits to schools for handicapped children I had the opportunity to observe these different teaching methods, which according to the teachers, were adaptations of more general teaching methods.

resource room. On the other hand, for children who have severe physical and intellectual disorders, traditional educational approaches do not fulfill their individual needs. Severely multiply handicapped children are best served in small special classes in which appropriate educational methods are tailored to their particular needs. These are the methods that I discuss in this chapter.

Special educational methods can be classified into three categories: behavior analysis, task-analysis, and diagnostic-remediation. The underlying concept in these methods is the idea of remediating a particular deficiency (Haring and Bateman, 1977). Remedial teaching differs from developmental teaching in the sense that remediation refers to those things we decide to do to, for, or with, a child after we have diagnosed the problem -- we feel that we know what the child does not know yet and needs to know. Developmental teaching is the regular program of instruction that children are exposed to in general classroom, and assumes a relative balance of development and achievement. When this balance is not present, we move into remedial teaching, which has the advantage of a restricted student-teacher ratio, availability of rich and varied materials, instruction based on individual diagnosis, and freedom to select materials without the restraints of a prescribed curriculum.

The behavior analysis method is derived from the principles of behavior modification. Basically, a sequence of steps is determined, beginning with what the child can do already, and performance on each successive step is rewarded. This method is especially effective in physical, speech, or occupational therapy. Rugel, Mattingly, Eichinger, and May (1971) describe an application of behavior analysis in which an 8-year-old quadriplegic cerebral palsied boy was taught gradually to place more weight on his feet when he stood up, instead of slumping on his arms when using a walker or standing at a table. This enabled him to use his hands and arms for such things as writing or drawing, instead of for support.

The task-analysis method consists of analyzing a particular task in terms of basic skills. These skills are then classified in terms of degree of difficulty. Instruction begins with the simplest skill,

and gradually more complex skills are introduced, until the child is able to master the task. Thus, the central idea of the task-analysis method is to teach directly the skills that are needed to achieve academic or behavioral objectives (Haring and Bateman, 1977). An example of an educational program based on the task-analysis principles is the DISTAR (Direct Instructional System for Teaching Arithmetic and Reading) program.

The diagnostic-remediation method views deficient abilities as the proper focus of teaching. It is based on the idea that we can identify what a weakness is, what is a reasonable way to measure the "distance" between the deficiency and the "cure," and what the paths and vehicles towards "recovery" are. Components of perception such as figure-ground perception, auditory and visual perception, and spatial notions such as position in space, are identified, tests are constructed, and remediation strategies are devised to teach the identified deficiencies (Haring and Bateman, 1977).

In the discussion that follows I pay particular attention to the task-analysis and the diagnostic-remediation approaches because they are related to the approach I used in the Logo environment.[1] The objective of this discussion is to compare these methods with the techniques used in Logo, and to show that task-analysis and diagnostic-remediation techniques are essential components of the Logo activities that I developed with cerebral palsied children. However, the objectives for using these techniques were different from those reported in the cerebral palsied literature. My aim was not to identify subskills of a particular task, but to allow the child to make sense of the task in his own way, i.e. to let the child to identify the subskills. Then, as problems arose, my role was to understand which of the child's subskills were deficient so I could help the child to overcome them. This is a fundamental difference because it amounts to who has control over the learning process. According to the description of the task-analysis and the

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1. For those interested in the behavior analysis approach see Introduction to Learning Disabilities: A Psycho-Behavioral Approach, by Daniel P. Hallahan and James M. Kauffman, Prentice-Hall, Englewood Cliffs, New Jersey, 1976.

diagnostic-remediation methods, it is clear that this control is in the hands of the instructor. It is his or her function to analyze the task, to choose diagnostic tools to evaluate the child's needs, and to prescribe remedial instruction programs. In the Logo environment, the child is in control. It is the child's knowledge and capacity to solve the task that determines the subskills he needs to master in order to succeed. The instructor's role is one of a facilitator, identifying skills that are deficient, and creating activities that involve these skills so the child can master them. Thus, in Logo what is important is not what the teacher knows and how he understands the task, but what the child knows and how the child makes sense of the task being performed. This point will be discussed in length in the next sections.

2.2 Task-Analysis Method

The task-analysis method of teaching was developed, partially, to satisfy the current demand that schools become more accountable for communicating their objectives and for their actual accomplishments in teaching basic skills. As Haring, Bateman, and Carmine (1977) have pointed out, this method represents a trend in special education "that shifts some attention from the child's strengths, weaknesses, or special etiology to an individualized remediation program for the task the child must learn. For the program's developers, this shift of emphasis away from the studying the child to studying the task is the result of an analysis of what teaching really is" (p. 166). The proposal of task-analysis is to stop laying the blame for failure on the child's physical and intellectual deficiencies. If the the child has not learned certain skills, remedial education should follow -- skills that have not been mastered must be directly taught.

The task-analysis remediation method consists of examining the task that the child must be able to perform -- reading, for example -- breaking the task down into its components parts, and teaching these components in an orderly, straightforward presentation. The identification of subskills and how to teach them are based on the program developer's understanding of the task. For example, DISTAR (Direct Instructional System for Teaching Arithmetic and Reading) is a language, arithmetic, and reading teaching program that encompasses all the essential aspects of

task-analysis and programming instruction. The designers of DISTAR have "developed a way of analyzing tasks that isolates the general concept or skill to be taught, and a way to program in which this general case is presented so impeccably that every child can learn it" (Haring and Bateman, 1977, p. 168). The first group of tasks in DISTAR, "Description of Objects," teaches the following skills: naming common objects, making statements that identify common objects, making "not" statement, describing the properties of objects, making plural statements, and making comparative statements. This example illustrates the principles underlying the task-analysis method and it shows how task-analysis can be used to develop instruction material.

This method has been widely used to teach handicapped children. Bigge and O'Donnell (1976) devoted their entire book to the application of task-analysis to teach academic, behavior, and living skills to individuals with physical and multiple disabilities. As an example of how to use the method, they describe a task-analysis for the language development of an 8-year-old girl with cerebral palsy. Based on the analysis of her errors, instructional objectives and a teaching plan were developed. The educational plan assigned to the girl consisted of instruction of the DISTAR language program. Once this decision was made, the girl had to follow a series of instructional and evaluation activities which culminated in the improvement of her language skills.

The DISTAR program has been successfully used with children with learning difficulties (Haring and Bateman, 1977) and I do not intend to criticize its effectiveness in teaching basic skills to these children. However, what surprises me about DISTAR is the extent to which control of the learning process is removed from the child. The program developers decide which word the child has to learn, the instructional pacing, the sequence of items, how much practice the child needs, and when and how to evaluate the child's development. The learner merely follows instructions and has no participation in their establishment. Probably Haring, Bateman and Carmine (1977) are right to affirm that this is what teaching really is; I doubt, however, that this is what learning should be.

This criticism applies to both the teachers as well the learners. In the teachers' case, by withholding the possibility of developing educational practices derived from the actual problems they face in their classroom, we are taking away the creative and innovative aspects of teaching. Machines can do the same or even a better job. And they will! In a recently national conference on the use of microcomputer in special education I was surprised to find how much software has been developed to teach children with learning difficulties.[1] These teaching programs can provide the information to the learner in an even more "patient" and "impeccable" ways than can most teachers. But is it what we want education to be, the mere delivery of preprocessed instruction to the learner! From the learner's point of view the situation is even worse. For example, if cerebral palsied children, who, as we have seen, have few opportunities to exercise their ability to make decisions, are placed in a situation in which things are dictated to them, this would be completely opposed to what an effective education should be. These children should be put in a position of making decisions about the activities they want to develop; they should be able to express their desires to create something; they should be able to face the consequences of their own acts. A normal child may be able to compensate for this debilitating educational experience by exercising these capacities outside the school. But for a physically handicapped child, going to school is frequently the only activity that takes place in his whole day. If the school denies him the ability to take chances and to be responsible for his own intellectual development, the school is not fulfilling its role as an institution that should provide these children with the experience required for them to compensate for their limited interaction with the world. It seems, then, that the education of physically handicapped children should be guided by the child's needs, rather than by what the educators decide it is essential for these children to learn. This is a central point in Logo.

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1. I refer to the "National Conference on The Use of Microcomputers in Special Education," sponsored by The Council for Exceptional Children, in March 10-12, 1983, Hartfort, Connecticut.

2.3 Diagnostic-Remediation Method

The basic difference between the task-analysis and the diagnostic-remediation approaches, as described in the literature, is that the former is used when the child's inadequate performance is viewed as the result of inappropriate teaching (Haring and Bateman, 1977). In the diagnostic-remediation approach the child's inadequate performance is viewed in terms of deficiencies within the child, and appropriate remedial education programs are tailored to overcome these deficiencies. Typically the child's cognitive, perceptual, and sensory-motor processes are assessed by a variety of psychoeducational instruments, and patterns of strong and weak functioning are identified. Then, remedial programs can be designed according to two rationales: the "teach-to-weakness" approach, which proposes that the disabilities should be remediated first; and the "teach-to-strength" rationale, which proposes that instruction should be redirected to those channels and processes through which the child learns more easily (Haring and Bateman, 1977).

The diagnostic-remedial approach is based on two important premises: (a) deficiencies in psychological processes can be reliably and validly assessed; and (b) remediation of these processes will result in improved academic performance. However, neither of these premises have been supported by experimental data (Haring and Bateman, 1977). Nevertheless this approach has been widely used by educators of handicapped children, and educational programs based on this idea continue to flourish. In this section I will discuss the process of diagnosing the psychological and educational disorders of cerebral palsied children, and the design of remedial programs that have been commonly used.

2.3.1 The Diagnostic Process

The choice of procedures used in the identification and evaluation of cerebral palsied children's learning difficulties depends on many factors including the diagnostician's philosophy regarding the nature and purpose of education, the professional training and skills of the people dealing with the children, time and funds available for diagnosis, and possible limitations imposed by the

child's age and physical impairment. Within this framework the "psychological and educational evaluation of a physically handicapped person should yield the following information to assist the establishment of educational goal: current levels of social maturity and educational achievement, aptitude for future learning, relative strengths and weaknesses in achievement and learning style, and the existence or possibility of barriers to the fulfillment of the person's academic potential" (Calhoun and Hawisher, 1979, p. 133). To collect this information the Education for All Handicapped Children Act (Public Law 94-142), requires that valid assessment instruments be administered by trained personnel according to the publisher's directions, that the manner in which the assessment is conducted should not bias the results obtained (i.e., a deaf child should not be given a verbal test), and that no single procedure or test should be used in establishing an educational program.

These legal requirements present several problems and seem to be contradictory if we keep in mind the kinds of motor and sensorial disorders cerebral palsied children have. The positive aspect of such an evaluation is that it has great potential to benefit these children. It can open the doors to appropriate and effective learning situations, meaningful personal and vocational guidance, and realistic planning for the future. However, this potential can be realized only if the evaluation process is flexible, creative, and approached through the use of adequate assessment tools. Yet, the very opposite of these conditions are exactly what typify traditional psychological testing, and the difficulties become even more dramatic when we consider the physically handicap. Some examiners' lack of experience with physically handicapped children, as well as the scarcity of suitable assessment instruments, has greatly limited the effectiveness of evaluations. As Cruickshank, Hallahan, and Bice (1976a), have indicated, there is no single test which is specific to this group of children, and the best tests in their opinion "all contain items which are inappropriate to cerebral palsied individuals or are in fact beyond their accomplishment at all due to their physical impairment" (p. 121). Such inadequate evaluations have been counterproductive and even punitive because they have let diagnosticians make the mistake of overestimating children's abilities by assuming undisclosed, unprovable, and possibly

nonexistent potential (Byers, 1971).

The problem of finding the appropriate instrument to estimate the overall intellectual potential of physically handicapped children has been approached by adapting existent standardized tests. These adaptations can be made at several levels. For the child with poor speech but good use of hands, performance tests are best indicated. For example, Cruickshank, Hallahan, and Bice (1976a) suggest the following tools: the Ravens Progressive Matrices, a nonverbal analogy test in which the child selects the proper elements for completion of an abstract design; the Columbia Test of Mental Maturity, which requires no verbal response and only a minimal motor response to select the right multiple choice answer to 100 questions; or the Peabody Picture Vocabulary Test, which yields a language score and requires that the child indicates the picture named from a selection of four choices. For children with functional speech but poor motor control, verbal tests take priority such as, the verbal portion of the Wechsler (WISC), or portions of the Illinois Test of Psycholinguistic Abilities. These assessment alternatives, although having the distinct advantage of being within the range of physical capabilities for handicapped children, have been criticized because they do not assess a full range of cognitive abilities. First, as Nicholson (1970) has suggested, the Peabody Picture Vocabulary Test evaluates only concrete mental skills through assessment of vocabulary, while the Columbia Test of Mental Maturity evaluates concrete as well as some abstract concepts through a single task, and the Ravens Progressive Matrices Test evaluates abstract concepts only. Second, most of these pictorial tests are designed with the objective of evaluating the perceptual component of the child's intellectual capabilities. This is not surprising because, as indicated in the previous chapter, in the case of cerebral palsy, perception disorders have been the main concern of researchers working with these children.

In addition to the criticisms mentioned in the previous chapter, and indeed the criticisms described above, the diagnostic tools used to evaluate the psychological and educational abilities of physically handicapped children present other problems. First, the simplifications that have been introduced in these tests to accommodate the physical and verbal impairment of these

children may lead to an underestimation of the child's true potential. For example, by using tests that only require the child to point or indicate one of the choices, we do not have any way of evaluating the process the child uses to find a particular answer. The child reaches a solution and we have no way of knowing the steps he used to come to that solution. Thus, these multiple choices tests give an impoverished view of the child's intellectual capability which may not lead to the selection of the most effective remedial program. This criticism is true for all multiple-choice tests, regardless of population tested. However, the problem with physically handicapped becomes even more dramatic because the child's evaluation, in general, is entirely based upon results of multiple-choice tests. Second, the selection of tests to use and the particular aspects of the child's abilities to evaluate are solely determined by the diagnostician. This "top-down" testing approach creates an artificial testing situation which can lead to a distorted evaluation of the child's abilities. The children may know that what they have been asked to perform is beyond their physical capacities and therefore may not become engaged with the test materials, or the child knows that he has been placed in a position in which he is being evaluated and may not want to show his weaknesses. While evaluating the ability of cerebral palsied children to seriate, I faced this situation several times. Some severely handicapped children avoid the testing situation and only agreed to participate in the experiment because they would have a chance to play with the computer. Another child, before getting involved in the experiment, asked several questions about the objective of the project. She explained that her inquires were based on her involvement in previous experiments. She knew that she had not done well, but there was no way she could tell whether something would come out of that study that would benefit her.

An adequate solution to the problem of diagnosing strengths and weaknesses in children physically handicapped should not rely solely on the use of standardized tests or modified versions of them. A comprehensive evaluation of the child's intellectual and educational abilities should involve a combination of standardized tests, tasks that the child has interest in fulfilling, as well as tasks that allow a diagnosis of the process the child uses to reach a particular solution. This is one of the objectives of providing physically handicapped children access to the Logo learning

environment.

2.3.2 Remedial Programs

Once it has been established through various assessment procedures that a child does have intellectual or educational dysfunction, remedial programs are prescribed to overcome these disorders. This typically consists of making specific educational recommendations for the use of materials or techniques other than those routinely employed in the regular classroom. This prescription is based, implicitly or explicitly, on a model of cognitive-perceptual functioning which guides the diagnostician in selecting remedial activities. In the case of cerebral palsy, as I have mentioned in the previous chapter, theoreticians and researchers in this area have tended to highlight the significance of perceptual and perceptual-motor development on maldevelopment in cerebral palsied children. This tendency does not merely indicate concern for perceptual disability per se, but what researchers are most interested, is the deleterious effects of such impairment upon children's learning and academic achievement. Thus, most of the remedial techniques and materials reported in the literature involve the remediation of perceptual functions in cerebral palsied children. This remediation is planned to overcome or circumvent alleged perceptual deficit in the hope that this will either alleviate the academic problem or lay a foundation for the development of academic skills. However, it is important to notice that the efficacy of inferring remedial procedures from the diagnostic process still awaits definitive support (Haring and Bateman, 1977). Some of these training programs do tend to increase the handicapped person's perceptual abilities, but there is no evidence that academic performance gets better (Haring and Bateman, 1977).

The remedial programs that have been recommended for use by cerebral palsied children can be divided into categories: programs that manipulate the learning environment, and recommendations of specific activities or materials to be used with these children. Although these recommendations cannot be separated in practice, in the following sections I discuss them separately.

2.3.2.1 Learning Environment

The term learning environment in the physically handicapped literature refers to the type of school and classroom arrangement. The recommendations that educators and clinicians suggest are based on the idea that handicapped children should be served in those learning environments that best meet their special needs. The degree of mental retardation, the degree of restricted communication, and the degree of impaired motor ability, all of varying proportions, require services that are the epitome of individualization; therefore for some children, the best learning environment is not a regular classroom. A severely multiple handicapped child is often best served in a small special class with intensive one-to-one learning experiences and therapy.

The organization of the learning environment and the design of activities that are recommended depend upon the diagnostician's philosophy regarding the nature of the child's disorders and how to overcome these disorders. For example, Cruickshank and his co-workers have proposed a model learning environment based upon their experimental findings. As it was mentioned in Section 1.3.2, they found that cerebral palsied children had attention deficiencies characterized by forced responsiveness to stimuli. According to Cruickshank and Dolphin (1951), this deficit operates to the child's detriment in any situation in which the required behavior calls for attention or concentration. Cruickshank (1976b) suggested that when attention deficiencies are found, the learning environment for these children be as free from stimulation as possible. He describes this nonstimulating learning environment as follows:

> Paper may be placed over windows to prevent the child from being distracted by visual stimuli outside the room or building. The room may be built without windows entirely. Some have removed transparent window lights and have substituted translucent or opaque lights. The room itself may be painted a single soft color, including the ceiling, walls, floor, and permanent furniture. Pictures and other stimulating material should be removed from the walls. In certain instances walls next to hallways and ceiling have been sound-treated to prevent extraneous auditory stimuli from penetrating the learning situation. A small room has been found to be more satisfactory than a large room....The goal throughout is not to make an uninteresting room, but to provide a learning environment for the child during those periods when his attention is demanded upon teaching materials. (p. 414)

The notion of contrived learning environment seemed to have played an important role in Cruickshank's development of remedial programs for cerebral palsied children. He devoted an entire chapter to the problem of designing learning environments for these children,[1] and conducted a two-year demonstration pilot study to explore the efficacy of such learning environment (Hallahan and Cruickshank, 1973). In this two-year pilot study, at the end of the first year, a comparison between the experimental group receiving the structured program and the control group receiving the traditional special-class curriculum indicated that the former group had made significant improvement on a series of perceptual tasks and on the ability to withstand distraction from background stimuli on the Syracuse Visual Figure Background Test. However, no significant differences were found between the two groups with regard to IQ or social development. At the end of the second year, a follow-up study was conducted. During the the twelve-month interim between these studies, none of the children from either group was in a classroom with a physical environment similar to that of the experimental group in the original program. Nor was there any attempt by the teacher to continue the highly structured curriculum of the project. The results showed that the experimental subjects had lost the advantages they gained during the demonstration project (Hallahan and Cruickshank, 1973).

Although the solution proposed is quite logical -- i.e., if the child is distractible environmental stimuli should be reduced -- the problem with Cruickshank's recommendation is that it tries to deal with a very narrow aspect of the handicapped child's deficiencies. This approach lacks a full understanding of the complex interrelations of intellectual and emotional functions. It does not consider, for example, that the child may have these attentional problems because the child's understanding of the world is impoverished because of his limited interaction with it. The child may have attentional problems because his cognitive structure does not help him to discriminate the relevant information from the irrelevant ones. According to this view, the solution to reduce

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1. This chapter appears in Perceptual and Learning Disabilities in Children: Psychoeducational Practices., Vol. 1, edited by W. M. Cruickshank, and D. P. Hallahan, Syracuse University Press, Syracuse, New York, 1975.

the stimuli itself contributes to the child's cognitive underdevelopment. However, if we assume that children develop the ability to attend selectively to relevant information and to ignore the irrelevant (a view which has been substantiated by a series of experimental data , see Hallahan and Cruickshank, 1973), the learning environment needs to contain different properties in order for the child to exercise and expand his capacity to discriminate. This rich environment should facilitate the learner's ability to construct meaning from experience -- a movement toward self-growth achieved by acting and experiencing the consequences of their actions, by observing others, by imitating models, by talking, and by listening.

Since the stimuli-reduced environment was not educationally successful over the long run, this solution has been recommended only for hyperactive and mentally retarded children (Hallahan and Cruickshank, 1973). The recommendation that has been suggested for the education of physically handicapped children try to provide these children with environments that are rich in terms of physical and social experiences. Calhoun and Hawisher (1979) asserts that a combination of special class and regular classroom placement is the ideal situation for many physical handicapped children. This idea is justified on the basis that the handicapped child needs the opportunity to have normal models and to interact with non-handicapped. On the other hand, special class placement has the advantage of providing the handicapped child with role models who are themselves handicapped and who have made a successful adjustment.

The recommendation of placing physically handicapped children in a less restrictive environment is oriented toward the idea of providing primarily a social setting. The literature does not mention specific activities teachers should develop in this less restrictive environment, or what features this environment should have or should provide. If a teacher wants to know what to do with a particular physically handicapped child it is very unlikely he or she is going to find specific suggestions in the literature. Most of the suggestions offered are quite ambiquious and demand a great deal of improvisation from educators. I think this is appropriate. If we consider each child's needs, it is impossible to enumerate a solution for each case. We should,

however, provide teachers with a certain degree of structure so they can function more effectively. This structure should not be a detailed description of the environment; rather the structure should be dictated by the activity the child has selected to initiate. This is another important idea in Logo, and will be discussed later.

2.3.2.2 Educational Material and Activities

The same philosophy of improving perceptual skills that has guided the design of learning environment has been also used to design educational materials and academic activities. For example, the idea of reducing external stimuli has been carried into the preparation of learning materials. Cruickshank (1976b) suggests that best reading books for cerebral palsied children should be the ones in which pictures are deleted or reduced in stimulation value, and that every task the child has to perform should be done in a situation of minimum background stimulation.

Remedial programs for aiding children with perceptual-motor disorders have been proposed by a number of researchers. These programs were mainly developed for children with learning disabilities and have been adapted for use by cerebral palsied children (Cruickshank, 1976b). The idea behind remediation of perceptual-motor functions is that there is a close relationship between perception and cognition. Werner has hypothesized that the child's perception of an object is largely determined by the kinds of things he can actively do with it. It was the opinion of Werner and Strauss (mentioned in Hallahan and Cruickshank, 1973) that damage to the central nervous system results in lack of advancement beyond a primitive, perceptual-motor-based thought stage. Consequently, they contend that the bizarre perceptual abnormalities experienced by brain damaged children are at the root of inferior concept formation. Because of the educational implications of this assumption there has been a natural movement in the learning disability field to consider the possible effects of perceptual factors upon academic achievement in general and upon reading in particular. The most prominent remedial programs emphasizing this approach are the perceptual-motor training programs developed by Newell Kephart, Gerald Getman, Ray Barsch, Marianne Frostig, Glen Doman, and Carl Delacato (Hallahan and

Cruickshank, 1973).

There are many similarities among the remedial programs developed by Kephart, Getman, Barsch and Frostig. All four of them, to a certain extent, share the Werner-Strauss orientation: they all agree that motor development is necessary for and precedes perceptual development, and they all believe that one needs to diagnose a child's particular problem before applying specific educational techniques. The programs of these four authors can be differentiated from one another, however, in the relative emphasis each places upon either visual or motor development. Viewed on a continuum of motor-to-visual orientation, Barsch can be found toward the motor end, while Getman exhibits a decidedly visual orientation, with Kephart and Frostig located toward the middle, with the latter leaning more toward the visual pole. Among these four researchers Frostig is the best known and her program has been the most extensively researched (Haring and Bateman, 1977). It includes exercises in: eye-motor coordination, which consists of drawing within boundaries provided on worksheets; figure-ground, consisting in finding and tracing figures embedded within other lines and figures; perceptual constancy, referring to the recognition that an object remains the same even though it may be presented in a different form, color, size, or context; position in space, requiring children to place themselves in various positions in relation to objects in the classroom, and to work with worksheets that require to discrimination of figures in various position; and spatial relations, consisting of activities in which the child is required to observe spatial relationships.

Doman and Delacato's program, on the other hand, places great emphasis on neurological organization as the basis of intellectual development. They instituted a program of intervention strategies which includes physical activities thought to induce correct neurological growth. For children unable to participate independently, the limbs were externally manipulated, often by a team of adults, and the exercises were carried out on an extremely rigid schedule. Their program came under serious attack for both the assumptions and the training techniques utilized, and the program has been censured by several professional organizations, including the American

Academy for Cerebral Palsy (Hallahan and Cruickshank, 1973).

Although these remedial programs have all been widely used, their efficacy has not been supported by experimental research. Hallahan and Cruickshank (1973) undertook an extensive review of the literature in order to determine the worth of perceptual-motor training programs. They categorized the studies on the basis of the population studied (learning disabled, mentally retarded, disadvantaged, and normals), and the program used (Kephart, Getman, Barsch, Frostig, and Doman-Delacato). The results showed that only seven of the forty-two studies reviewed were free from errors of faulty reporting, unsound methodological procedures, or both. With regard to the seven sound studies, there was no consistent trend within this limited sample of reports. For example, the Frostig training program was found to increase scores on the Frostig Developmental Tests of Visual Perception, but there was no evidence that it improved reading (Haring and Bateman, 1977).

The above programs are by no means the only ones that have been developed in an attempt to intervene in perceptual-motor development. They have had the greatest impact upon the field, and as Reid and Hresko (1981) have suggested, these researchers' contributions should be remembered not for what they failed to do but for the "catalytic force they provided for research into the functioning of the learning disabled child" (p. 79). The authors add that the field must go beyond the legacy that suggests that basic psychological functions have been disrupted in learning disabled children as a result of brain dysfunction.

An alternative educational approach has been offered by psychologists and educators actively involved in the cognitive movement in education. In general, their position holds that it is important to consider what happens *internally* to the person who is learning and to view learning as a construction process. According to this view it is the learner who is the most important element in the teaching-learning situation; not the material, lessons, teachers, classroom, or other factors external to the learner. The learner should be under control of his own learning, selecting his or her own topic for study. Rather than imposing a preestablished structure to the learning

situation, the teacher should devise a variety of approaches, and encourage the child to generate relevant relations between the new information and past experience. The educational approach recommended to be used with children with perceptual-motor disorders is summarized by Reid and Hresko (1981):

> We suggest only one approach for teachers of children with perceptual difficulties: teach the children to read, write, and do arithmetic! If, for example, a child is reversing letters, it does no good to instruct him in a perceptual program and hope for the reversals to eliminate themselves. Rather, the teacher should deal with the reversed letters directly. That most often means helping children become aware of the similarities and differences between letters and in focusing on their using syntactic and semantic cues as decoding aids. (p. 85)

2.4 The Educational Approach in the Logo Environment

The basic difference between the Logo educational approach and the task-analysis and diagnostic-remedial approaches is that in the Logo environment the **child** proposes the activities he wants to develop. The Logo teacher does not impose a particular task, or create artificial testing situations. The function of the teacher in Logo is to help the child to select a project that can be both fun and, at the same time, challenging for the child. This goal can be achieved by using the task-analysis and the diagnostic-remediation methods.

However, the intention of using the task-analysis method in Logo is quite different from the goals proposed in the special education literature. The main objective of task-analysis in Logo is to provide the teacher with information about the task the child is undertaking, rather than to empower the teacher with skills that are to be directly taught to the child. Similarly, the diagnosis of the child's intellectual capacities is based on the task that the child proposes. It is our conviction that this approach will allow us to get to know the individual potential in a much more realistic and meaningful way. This adds a flexible and creative aspect to the diagnostic process that is lacking in the traditional psychological testing.

The proposal I want to suggest is that we complement the traditional testing process with something that the child has interest in and is committed to develop. Hopefully, this will decrease

the likelihood on an evaluation which is totally under the control of the diagnostician, enhancing the possibilities of an evaluation in which the child also has some participation in the process of deciding which activity should be selected to assess his psychological and educational capacities. This can help us to make the testing process much more realistic, flexible, and creative.

Chapter 3

Research Proposal and Research Methodology

The objective of my research is to create a computer-based environment to study alternative solutions to the problem of assessing and educating physically handicapped children. The goal is to provide children handicapped by cerebral palsy with the opportunity to develop interesting, challenging, and revealing activities that have an educational, diagnostic, and remedial purpose -- activities that can foster a deeper understanding of these children's intellectual abilities, and can provide these children with both a chance to acquire knowledge and to overcome their particular intellectual deficiencies.

The research is divided into two studies. One study is to investigate how cerebral palsied children can use a computer system for performing constructional tasks; i.e., tasks that require the child to manipulate objects while constructing a particular pattern. This study is referred to as the Screen Task Study.

The other study, which is the major part of the research, is an indepth exploration, using Logo, of the nature of cerebral palsied children's cognitive deficiencies, questioning whether these deficiencies can be minimized by providing a Logo programming experience to these children. This study is referred to as the Case Studies.

3.1 The Screen Task Study

I have proposed that an adequate solution to the problem of diagnosing strengths and weaknesses in physically handicapped children should not rely solely on the use of standardized tests or modified versions of them. A comprehensive evaluation of the child's intellectual and

educational abilities should involve a combination of standardized tests, tasks that the child has interest in fulfilling, as well as tasks that allow a diagnosis of the process the child uses to reach a particular solution. The crucial question, however, is how can individuals with motor coordination difficulties, who cannot manipulate objects in the physical world, perform those tasks?

One solution to this problem is the development of a computer system that allows the implementation of performance tasks. Through this system, physically handicapped individuals can manipulate "objects" on the computer screen with minimal motor effort. The seriation task,[1] developed by Piaget (1965), was implemented in this computer system and used by several normal children and severely cerebral palsied children.

The seriation task was introduced by Piaget in connection with an investigation of how children develop concepts of number (Piaget, 1965). For Piaget, the ability to seriate is of great importance for the child because it forms the basis of several cognitive structure. For example, the concepts involved in seriation and classification together provide the support on which the conception of number is based. According to Furth (1969), the seriation task allowed Piaget to understand the general concepts of relation and order that are manifest in a great variety of numerical situations. The seriation task has been also used to investigate the relationship between perception and cognition (Inhelder and Piaget, 1964). As I have mentioned, it has been a common notion in developmental psychology that perception underlies later cognitive development. To show that this is not the case -- i.e., that the hierarchical relationship between perception and cognition does not exist, but rather perception is an aspect of cognitive structure -- Piaget and his co-workers employed a series of tasks, including the seriation task. They demonstrated that the configuration of ordered sticks contributes very little to the ability to seriate; that is, to be able to seriate it is not

1. The seriation task consists of presenting a set of sticks of different lengths, and asking the child to arrange the sticks in order, from the longest to the smallest.

enough the child to be aware of the form of the sticks final configuration, the child needs to apply a series of mental operations to be able to understand the relationships that hold the sticks together in a seriate form. (This point will be discussed in the next chapter.) For the moment it is important to mention that the distinction between the notion that perception is the basis of cognition, and that perception is part of cognition, is fundamental to the understanding of cerebral palsied children. It implies that we should not try to improve these children's perception abilities, but rather their capacity to know and to learn. This is one of the reasons I selected the seriation task to be used with cerebral palsied children. I want to show that the inability of cerebral palsied children to seriate is not due to their poor ability to perceive in the sense of becoming aware of spatial relationships. Rather, because these children lack certain abilities to coordinate relationships between size, they cannot develop, carry out, and correct a plan of action necessary to perform the seriation task. In addition, I selected the seriation task because it has several features that can help to demonstrate the usefulness of the computer system, as a way of helping physically handicapped children to perform a constructional task. When performing the seriation task the child has to use objects to construct a pattern, and the goal of the task is easy to understand. Plus, there is more than one strategy that can be used to solve the task, i.e., the task does not require the child to find a "trick" solution, rather he can use several paths to get to the correct task goal.

The objectives of the Screen Task Study are: (a) to determine whether severely motoric impaired children can benefit from a computer system to help them manipulate "objects" on the screen, thus making it possible to assess their intellectual development with performance, rather than multiple-choice, tasks; (b) to investigate whether the development of the capacity to seriate reaches a stage of stability after a certain age, as in the case of normal children; (c) to explore whether physically handicapped children are able to succeed in the seriation task, regardless of their degree of motor impairment; and (d) to study whether physically handicapped children approach the seriation task by adopting strategies that are similar to the ones adopted by normal children.

A general purpose computer system is developed for implementing a wide variety of tasks. New tasks can be added relatively easily. The system provides a series of features. A cursor can be moved to the north, south, east, and west parts of the screen by pushing the button which has an arrow pointing to each of these directions. Also, there are two buttons to rotate the cursor clockwise and counterclockwise, and there are "grasp" and "drop" buttons. An "object" can be moved to different places on the screen by having the cursor touch the object and then "grasping" it by pushing the "grasp" button. Once the object is grasped, pushing the directional buttons moves both the cursor and the object; pushing a rotational button rotates the cursor and the object. When the object has been moved to a desired location, it can be "dropped" by pushing the "drop" button. Thus, a physically impaired child can "manipulate" objects by just being able to push few buttons; buttons, incidentally, which can be pushed by any part of the child's body that has the necessary degree of controllable movement. Other features of the system include the provision of an automated record of the moves made by the subject, complete with a time marker; and a facility for using this record to provide a rerun of the task for purpose of analysis.

Since the screen version of the seriation task introduces new properties not present in the original task, it is necessary (and interesting) to compare the performances of nonhandicapped, normal children with those of physically handicapped children, doing each version of the task. To select the appropriate age level of nonhandicapped children to participate in the experiment, fourteen children, between the ages of 5 and 7 years (age in which children are supposed to learn to seriate), were asked to perform the screen seriation task as part of a pilot study. All children 7-years-old succeeded in the task, while children 6-years-old or younger had difficulties. Since the main interest was to understand the difficulties children have in performing the task, the age level of nonhandicapped children selected was between the ages of 4 years, who according to Piaget (1965) are unable to seriate, and 6 years, who still have difficulties with the task. Nine nonhandicapped normal children between the age of 4 and 6 years, and thirty-two severely cerebral palsied children, between 11- and 19-years-old, participated in the study. The cerebral palsied children were selected on the basis of their degree of motor impairment, rather than age.

The normal and the handicapped children were asked to perform both versions of the seriation task: the typical version of the task, using wooden sticks (following the method described by Elkind,1964); and the screen version, in which lines on the computer screen represented the sticks. (The experimental method was adapted from Elkind's methodology.)

3.2 The Case Studies

I have proposed that it is possible and desirable to create learning environments so that physically handicapped children can actively initiate and control the activities they want to develop, and that they have the opportunity to develop activities which directly tap their intellectual abilities.

The Logo environment was made available to several severely cerebral palsied children from the Cotting School for Handicapped Children. The goal of this project was to learn how the Logo environment could be used to increase the potential of these children. Their work indicated that each child had different difficulties, and different capabilities which were not directly proportional to their degree of motor impairment, as determined by behavioral indices. This finding was supported by the results of the Screen Task Study, since the cerebral palsied children's ability to seriate was not significantly correlated with their degree of motor impairment, confirming the notion that cerebral palsied children are a heterogeneous group regarding to intellectual capabilities. In view of these results I decided to describe indepth studies of a few children. This way I would be able to pay particular attention to idiosyncrasies, and to trace patterns of skills development involved in the use of the computer.

Among the seven children who participated in the project I chose to describe the work of three of them: Mike, a quadriplegic boy, who was 17-years-old when he began to participate in the project; James, a quadriplegic spastic boy, who was 13-years-old when he started to work with the computer; and Kate, a quadriplegic spastic girl, who was 13-years-old when she became involved in the project. Each child worked with the computer individually. I took notes on each child's

project, ideas, and difficulties, and the system kept a dribble file [1] of their computer work.

Mike is the student who spent the longest time in the project (in terms of hours of computer time) and who benefited most from the computer activity. His limited motor capacities drastically reduced his interaction with the physical world. Before the computer project, there were few things that Mike was able to do on his own. He always needed another person to implement his ideas. He is a typical case of a capable person with few opportunities to show his abilities -- a case of "trapped mind" which the computer helped to untrap. Mike began working with Logo in October, 1978 and he was involved in the research until the end of the 1981 school year, when he graduated from high school. His Logo activities were developed on the 3500 microcomputer, [2] and he spent approximately 10 hours per week working on the computer. Mike's entire computer work was recorded on dribble files.

James joined the research in April, 1979 and Kate started in September, 1979. Both participated in the research until the end of the 1982 school year. During this time they each had two 50-minute sessions per week. James' computer work indicated a series of idiosyncrasies that made him quite different from the other cerebral palsied children. For example, his computer activities show that his writing skills were much superior than to his abilities to use Logo commands to produce geometrical drawings. This created an unique opportunity to investigate the reasons for his disabilities in commanding the Turtle, and the opportunity to design remedial computer activities to help James to develop some of the concepts necessary for his drawing activities.

Kate, on the other hand, presented overall cognitive disabilities. She did not have James'

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1. The dribble file is a computer file in which every character that is typed in the computer keyboard is recorded. This file is printed at the end of each session and the printout is kept as part of the student's work.

2. The 3500 microcomputer was designed by Professor Marvin Minsky of the Artificial Intelligence Laboratory of M.I.T.. This was the first attempt to implement Logo in a small computer. The 3500 microcomputer is no longer available in the market, and Logo has been implemented in several microcomputers, including Apple, Atari, and IBM.

linguistic strengths, and her drawing activities demonstrated similar problems to those experienced by James. She is an example of how a computer learning environment can be adaptable to accommodate the needs of a child with low intellectual capacity. The remedial program designed for Kate was to help her to become more independent and to learn how to control her own activities.

The initial computer activities with James and Kate took place on the 3500 microcomputer, (in February, 1981 they started using the Apple II Plus microcomputer). The work developed on the 3500 microcomputer was recorded on dribble files, and during the time they used the Apple microcomputer I took notes of their computer activities, as well as observations of their behavior while at the computer.[1]

The goals of these case studies were: (a) to try to help these children improve their problem-solving abilities by all means possible -- this would elucidate the general question of whether their deficiencies were due to lack of problem-solving experience; (b) to analyze the specific pathways to improvement, in particular to distinguish between having knowledge, being able to access the knowledge, and becoming more critical about self-performance -- this would help to answer the question of whether the computer environment fosters critical and analytical skills which are essential to problem-solving processes; (c) to dissect as far as possible the specific contributions of the use of the computer -- this would illuminate questions about the possibility of getting similar results with other educational materials; and (d) to understand general aspects of the learning process -- this would help us to develop more effective computer-based learning environments.

1. The Apple microcomputer does not have the facility to keep automatic dribble file, as did the 3500 microcomputer.

Chapter 4

The Cerebral Palsied Child's Ability to Perform the Seriation Task

The objectives of the study described in this chapter are twofold. First, to investigate how cerebral palsied children of different ages and degree of physical impairment perform in the seriation task. Second, to explore whether a computer system could be used as a way of implementing performance tasks to assess the intellectual abilities of severely physically handicapped children. This computer system was used to implement the seriation task. Twenty-three nonhandicapped normal children, and thirty-two severely cerebral palsied children, participated in this study. These children were asked to perform the real and the computer versions of the seriation task.

In this chapter I analyze the concepts involved in the seriation task, I describe the performance of normal and cerebral palsied children in both versions of the task, and I discuss the the usefulness of the computer system. The results of this study show that normal children are able to solve the seriation task at a much younger age than the children with cerebral palsy. However, the strategies used by cerebral palsied children to perform the seriation task were not different from the strategies adopted by normal children. This indicates that the cerebral palsied children's capacity to seriate is delayed rather than deviated from the normal pattern of development. Further analysis of the data from the handicapped population shows that the cerebral palsied child's ability to perform the task is not significantly correlated with the child's age or degree of motor disability. Thus, for some of the children with cerebral palsy, intellectual capacity is not improving with age, and, furthermore, one cannot assume that extensive physical impairment implies severe cognitive disability. These findings: (a) lead us to question some of the traditional assumptions about the intellectual development of cerebral palsied children; and (b) indicate that the task of educating these children is vastly complex, necessitating individualized instruction. In addition, the results show that the computer system is a useful assessment tool to be used with physically handicapped children. This is discussed in conjunction with a comparison of normal and cerebral palsied children's performances in both versions of the seriation task.

4.1 Introduction

I have proposed in previous chapters that the intellectual deficiencies in cerebral palsied children are of a cognitive nature, rather than perceptual, as proposed in the cerebral palsy literature. Several recent studies have been conducted to investigate cognitive development in cerebral palsied children. Sternlieb (1977), for example, has studied the development of cognitive structures in cerebral palsied children and has found that, compared with normal children, there is a two to three year developmental lag in the acquisition of both space-related and non-space-related cognitive structures. This developmental delay has been attributed to these children's lack of sensory-motor experience.

However, most of these cognitive studies with cerebral palsied children, including Sternlieb's, have used multiple-choice tasks, adapted from original tasks developed to be used with normal children. The reason for using multiple-choice tasks is that cerebral palsied children's motor impairment prevent them from performing other type of tasks. As I have mentioned in Chapter 2, however it can be misleading to assess physically handicapped children with only multiple-choice tasks. The problem is that these tasks do not allow researchers to understand the process the child uses to solve the task. I have argued that a more complete picture of the child's true potential should involve a combination of tasks, including constructional tasks in which the handicapped child has to manipulate objects, thus creating a situation that allows the observation of the child's intellectual processes.

The study described in this chapter is an attempt to demonstrate how we can adapt performance tasks so that physically handicapped individuals can perform them. A computer system was developed in which "objects" on the computer screen can be "manipulated" by hitting keys on the computer keyboard. The seriation task was implemented in this system, and several physically handicapped children used it.

The seriation task was selected because it has several features: it is a task in which the child has to use objects to construct a pattern; the goal of the task is easy to understand; and there are more

than one strategy that can be used to solve the task. The objectives of this study were: (a) to investigate whether severe motoricly children would benefit from a computer system to help them manipulate "objects" on the screen, thus making it possible to assess their intellectual development with performance tasks, rather than multiple-choice tasks; (b) to determine whether the development of the capacity to seriate would reach a stage of stability after a certain age, as in the case of normal children; (c) to explore whether physically handicapped children would be able to succeed in the seriation task, regardless of their degree of motor impairment; and (d) to study whether physically handicapped children would approach the seriation task by adopting strategies that are similar to ones adopted by normal children.

4.2 The Seriation Task

The seriation task, as developed by Piaget (1965), consists of presenting a set of sticks of varying lengths and asking the child to arrange these sticks in order from the biggest to the smallest, and to insert extra sticks in the right place so a "stairway" configuration can be maintained. The seriation task that I used is based upon Elkind's (1964) standardized version of Piaget's original task. It has two parts. The first part consists of presenting to the child the seriation goal, i.e., what he will be asked to achieve, as shown in Figure 4.1a. This is described to the child as being a "stairway." In the second part, the sticks are clustered, as shown in Figure 4.1b. The child, then, is asked to construct the seriation goal state. After the series is constructed, a second set of sticks is given and the child is asked to insert them within the stairway.

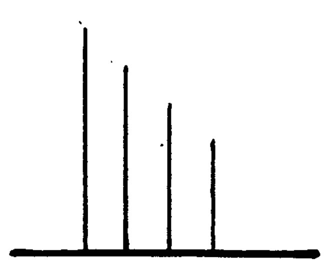

Figure 4.1a

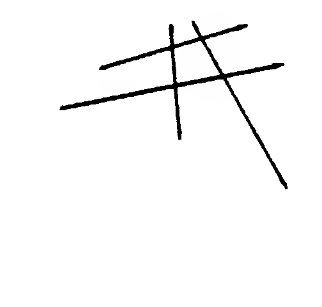

Figure 4.1b

Thus, there are two subtasks the child has to perform in order to seriate the sticks: to construct a mental representation of the seriation goal state, and to develop and carry out a plan to order the sticks.

The seriation task was introduced by Piaget in connection with an investigation of how children elaborate relational structures with regard to the concept of number, such as the concepts of relation and ordering (Piaget, 1965). The task has been used by Piaget and his co-workers to study other aspects of children's intellectual development. The most relevant work concerns the formation of operations of classification and seriation (Inhelder and Piaget, 1964). These studies have shown that children's abilities to seriate progresses through three distinct stages. In the first stage (usually at the age of 4 years) the child fails to construct the complete series, and succeeds only in making partial series, i.e., several series of a few sticks which the child puts side-by-side without regard to the order of the whole series. In the second stage (usually at age 5) the child succeeds in making a correct seriation by trial and error. The child at this stage has difficulty eliminating errors and cannot insert extra sticks in the completed series. Finally, in the third stage (usually at age 6 or 7), the child is able to seriate and insert the sticks correctly. This finding has been confirmed by other researchers (Elkind, 1964; Gillieron, 1977; Hood, 1962; Murray and Youniss, 1968; Young, 1973).

4.3 Analysis of the Seriation Task

Although the child's capacity to seriate has been classified into three age-stages, Frey (1964) and Gillieron (1977) have indicated that it is possible to succeed in this task by adopting more than one strategy. The multiplicity of ways to seriate the sticks may correspond to a multiplicity of problem-solving abilities, and, therefore, to different developmental levels. Based upon this hypothesis they developed several procedures to show the different ways by which the correct order of the sticks can be achieved. These procedures show the different types of knowledge involved in the solution of the task and how these types of knowledge are used to succeed in seriating the sticks.

I utilize these authors results, as well as findings of other researchers, to analyze the seriation task, and to identify the different types of knowledge involved. I analyze the task in terms of subtasks: the kind of mental representation the child can use to represent the seriation goal state, and the strategies that can be used to solve the task. The results of this analysis is used later to analyze the children's performance, and to describe their behavior while performing the task.

4.3.1. Representation of the Seriation Goal State

The first problem the child has to face in the seriation task is how to represent the seriation goal state. This can be done in terms of mental images, or symbolic representation, such as words. The imagistic representation may consist of a picture of the whole pattern, or of images that represent features of the pattern. The symbolic representation may be a word that describes the whole configuration, such as the word "stairway," or a sentence that describes several features of the pattern, such as "The sticks are perpendicular to the line, equally spaced, and arranged from the biggest to the smallest." The main distinction here is that the representation of the whole pattern, either through mental image or symbolic representation, imposes an implicit unity on the configuration of sticks as if it is formed of undifferentiated parts. The representation of features consists of relationships the child extracts from the whole pattern.

The type of mental representation the child selects has an intimate relation to the child's selection of strategy and, thus the ability to seriate the sticks. For example, a wholistic representation has an ultimate effect in the overall performance of the child. Elkind (1964) hypothesized that the reason children of the second stage use the trial-and-error method and the reason they cannot insert an extra stick within the completed configuration is related to the imaged character of their representation.

> ...the second-stage child imagines the stairway to be a set of elements related only by the fact that they join to form a pattern; consequently, when the child tries to reconstruct the pattern from a set of unordered elements, he regards each element as unique. He can think of no systematic way of selecting them. [p. 289]

An unsystematic way of selecting the sticks may lead to a final configuration that differs from the

representation. The child, then, begins to coordinate the relative size relation among the sticks by moving sticks to different positions until the final configuration matches his mental image. However, it is important to notice that the "good" configuration the child achieves "is neither spontaneous nor deduced and is achieved only because of the discrepancy between the imaged and the perceived figures" [Elkind, 1964, p. 289].

Although Elkind emphasizes only the image type of representation as responsible for the second-stage-child's behavior, it seems that the representation using the word "stairway" contributes to the same wholistic character of the stick configuration. The child's goal is to reach a configuration that looks like a stairway. The only difference is that instead of having a mental picture, the child adopts a name that can invoke that same picture.

The wholistic character of the representation could be responsible for the child's inability to insert extra sticks. As soon as he finishes constructing the series, the child regards it as a complete picture to which nothing more can be added. It is for this reason that when children of the second stage are given the extra sticks they cannot understand the experimenter's request and do one of three things: (a) they construct a second series alongside or atop the first; (b) they exchange sticks rather than add them; or (c) they insert sticks without regard to their size relations and regard such insertions as correct.

On the other hand, evidence indicates that children who develop a mental representation in terms of the key features of the seriation goal state can coordinate relations between the sticks and can extract these relations from the seriation goal state. The ability to notice the important features implies that the child can identify each stick's contribution to the whole configuration: each stick has a different size, each stick occupies a particular position in the configuration, and each stick is at the same time smaller than the sticks that follow it and larger than the sticks that precede it. As Piaget (1965) has observed, this coordination of relations cannot be achieved without a mental operation that (a) breaks the configuration into its constituent elements, (b) attributes to each stick the relation $B > A$ and $B < C$, and (c) combines these two relations to conclude that

$A < B < C$; i.e., that stick B is at the same time smaller than C and longer than A, which Inhelder and Piaget (1964) have called the reversibility concept.

Thus, the child's ability to represent the seriation goal state in terms of features of the patterns may account for two behaviors observable while the child is performing the task. First, it may account for the strategy the child adopts. For example, if the child describes the seriation goal state as "going from the biggest to the smallest," he may adopt a strategy that always selects the biggest stick from the pile and places it at right of the stick on the line. Through this strategy the configuration will grow according to the description he has adopted. Second, it accounts for the child's ability to insert extra sticks. A stick to be inserted, say B', presents to the child the same problem he encountered in the seriation of the sticks, namely, that of attributing two relations to B': $B' < C$ and $B < B'$. Thus, both seriation and insertion are achieved because the child can attribute to the configuration a series of mental operations that leads to a mental representation in terms of the salient features of the stick configuration -- which, in turn, facilitates the selection of appropriate strategies to solve the task.

It is clear that just having the mental representation of the whole configuration of sticks by itself contributes little to the ability to seriate. Inhelder and Piaget (1964) have shown this more clearly in a series of experiments using blocks with monotonically increasing or decreasing differences, so that the profile of the series is parabolic. The results of these experiments showed that not until the age of 9 or 10 can children use the global shape of a series to decide which of two distinct pairs of adjacent blocks differs by a greater amount. Younger children had to explicitly compare the pairs of blocks in order to make the decision. Thus, children do not use the configuration of the whole until a comparatively late age. The explanation proposed by Elkind (1964) is that "the internalization of ordering activities transforms the child's perception (and representation) of the series because he attributes to that perception the results of his own mental activity" (p. 290). The representation of the whole configuration is changed by the child's capability to perceive relationships. Thus, the stronger the cognitive structures the better the child is able to perceive. A

clear example of this is indicated by the inability of a nonmedical person to perceive relevant anatomical information from an X-ray. Only the "trained eye" of an expert is able to "read" the X-ray. This simple observation, as well as results of experiments such as those described by Inhelder and Piaget (1964), has been used to demonstrate that there is a strong relationship between perception and cognition. The view that perception forms the basis of cognition, although tempting to account for people's ability to perform tasks, does not hold true. We perceive things in the world according to our cognitive capacity. To be able to seriate the child needs to apply to the "good" configuration of sticks a series of mental operations to be able to understand the relationships that hold the sticks together in a "good" form.

4.3.2 Strategies to Order the Sticks

Gillieron (1977) has described three strategies that can be used to order a set of sticks of different length: successive elimination, insertion, and final places. These strategies differ in the emphasis that they place on the logical and spatial aspects of the seriation task. Gillieron (1977) further indicated that the construction of a series involves two aspects: a logical aspect, characterized by the establishment of relations and their coordination; and a spatial aspect, which is intimately related to the spatial order in which the sticks are placed on the final configuration. This distinction will be clear in the discussion of each strategy that follows.

4.3.2.1 Strategy of Successive Elimination

This strategy consists of selecting the longest of the remaining sticks from the pile and placing it to the right of the stick already on the line. To select the longest stick from the pile the child can proceed as follows:

1. take one stick from the pile and assume it is the longest (call it BIG).
2. begin a succession of comparisons with all the sticks in the pile.
3. if a longer stick than BIG is found, assume that BIG is this new stick. Then repeat steps 2 and 3.
4. if a longer stick than BIG is not found, then BIG is the longest stick.

Piaget and his co-workers have analyzed the behavior of their subjects in terms of this strategy. According to them this strategy requires the child to be able to anticipate that the seriation goal state will grow without any error. There are two characteristics in this strategy that indicates the concept of anticipation: the comparisons are made between the stick in hand and those stick still unplaced on the line, i.e., on the pile; and each stick, once selected, finds its definitive place on the line. Also, this strategy indicates that the child is taking into account all the relationships existing among the objects. By selecting the longest stick from the pile, the subject is assuming that this stick is shorter than the stick already on the line. This behavior implies the concept of reversibility, i.e., that a stick is at the same time longer and smaller than another stick. It is important to notice that the anticipatory and the reversibility concepts go hand in hand; they are the only concepts involved in this strategy. The concept of transitivity, i.e. if stick A is longer than stick B, and stick B is longer than stick C, then stick A is longer than C, is not used at all. As noticed by Frey (1964) the concept of transitivity only helps to reduce the number of comparisons made: the sticks that are smaller than the current BIG stick do not have to be compared with the new BIG.

Although the above algorithm to select sticks seems to require direct comparisons between sticks, we may have a variation of it in which the comparison in step 2 is not done directly, but rather mentally. However, the mental comparison makes it difficult to understand whether the child is taking the relationships among the sticks into account. Thus, depending upon how the child perform the selection of sticks we may not be able to decide whether he is using the relations between the sticks or not. What makes stage-three subjects distinctive is that once they select the longest stick they will ascertain its length dimension by making the necessary side-by-side comparisons.

4.3.2.2 Strategy of Insertion

Assuming that the seriation is going to be arranged from longest to smallest, from left to right respectively, this strategy consists of taking one stick of the pile and placing it on the line

according to the following algorithm:

1. take one stick from the pile
2. compare it with the stick on the line furthest to the left.
3. if bigger, place it to the left side of this stick.
4. if smaller then:
   4.1 if there is no more sticks to be compared on the line, place the stick to the end of the line.
   4.2 otherwise, compare the stick with the stick to the right and repeat steps 2 to 4.

This strategy is a good indication that the child knows the necessary concepts involved in the seriation task. First, it implies that the subject knows that the first pair of sticks he places on the line are the initial elements of the series. If these sticks are ordered correctly then the series will grow correctly. Second, the subject must have the anticipatory concept. This strategy implies that the child knows the seriation grows without any error since each placement includes the necessary controls. Third, the child must have the reversibility concept. It is easy to observe the use of this concept in the child's behavior because in order to apply this strategy he must compare a stick to be placed with the ones already placed. Fourth, the transitivity concept is not required by this strategy. Having this concept only helps to reduce the number of comparisons: instead of beginning the comparisons with the stick on the line furthest to the left, the child can start with the middle stick on the line and proceed the comparison with the sticks to the left of the middle stick if the stick is longer than the middle one, or to the right if smaller than the middle stick.

4.3.2.3 Strategy of Final Places

This strategy is not guided by a particular algorithm to either select or place the stick on the line. The child may select a stick either because it is near his hands, or the stick is on the top of the pile, or selection may be guided by no obvious rule. The placement of the stick on the line may be either to close a gap between two sticks, or the child may place it at one of the leading edges of the

series. The point is that when a stick is selected or placed on the line, no explicit comparison is made. There are no controls in the process of placing the sticks on the line, as there were in the previous strategies. After all of the sticks have been placed on the line, the child compares this series with his mental representation of the goal state. At this point if the child notices that the stick configuration does not match his mental representation, he begins to correct the series (to debug it). The debugging process may differ according to the child's developmental stage. Children at stage one may either compare sticks without coordinating the relationships between them -- these children may end up making pairs or triplets of ordered sticks, or they may concentrate on the general pattern of the series, obtaining, for example, a stairway whose sticks are not aligned at the bottom. Children of stage two may order the sticks by using trial-and-error. Their primarily aim is to get the pattern. Finally, children of stage three are able to use one of the previous algorithms to correct the series.

4.3.3 Summary of Concepts Involved

These three strategies show that in order to succeed in ordering the sticks the child needs to master different types of knowledge. First, the child should be able to identify that the sticks have different length. Second, the child should know that there are three different types of sticks: the longest, the shortest, and the sticks that fit in the middle. Siegel (1972) has shown that 3-year-old children have little difficulty identifying the end positions of the three and four objects series, but only children older than 6 can identify the inner positions of the series. Third, the child needs to be able to coordinate the relationship between sticks and understand the concept of reversibility. Fourth, the child needs to combine these different types of knowledge to develop a plan to construct the seriation goal state. This means that it is not only important to have the concepts, but that it is also important to know how to use these concepts to develop an algorithm that fits the task at hand. Fifth, the concept of transitivity is not a necessary concept to perform the task. Understanding transitivity merely helps to minimize the number of comparisons. Sixth, ordering the sticks is not a sufficient indication the child has mastered the notions involved in the task. For example, it is possible to obtain the seriation goal state by using strategy of final places

which does not require the coordination of relations between the sticks. The child indicates whether he has acquired this skill if he is able to justify his behavior by making comparisons between the sticks and been able to insert sticks to the already completed series.

4.4 Experimental Methodology

The research experiment consisted of asking nonhandicapped normal children and severely cerebral palsied children to perform two versions of the seriation task. The standard version of the task used wooden sticks and the experimental method described by Elkind (1964). The computer version used lines on the computer screen to represent the sticks, and the experimental method was adapted from Elkind's methodology.

4.4.1 Subjects

Twenty-three (23) nonhandicapped normal children from 4 to 7-years-old were tested as part of two pilot studies. Fourteen (14) children between 5 and 7-years-old from the Cambridge Alternative School participated on the first pilot study. The objective of this study was to investigate whether the computer version of the seriation task could be used to evaluate these children's ability to perform the task. These children only performed the computer version of the task. Nine (9) children from the M.I.T. Day Care Center between 4 and 6-years-old participated in the second pilot study. The objective of this second study was to test whether the experimental methodology I had developed was compatible with the methodology proposed by other researchers who have used the seriation task. I was particularly interested in finding whether the computer version of the task introduced new properties into the original seriation task. These children performed both versions of the seriation task.

Thirty-two (32) severely cerebral palsied children 11 and 19-years-old also participated in the experiment. These children were from the Cotting School for Handicapped Children, the Massachusetts Hospital School, and the Agassiz Village Summer Camp. The impairment of their upper (hands and arms) and lower (legs) limbs was classified according to the Pultibec System for the Medical Assessment of Handicapped Children (Lindon, 1963), a summary of which is

presented in the Appendix. In a scale of 1 (normal usage of limb) to 6 (complete useless of limb), the mean score of upper limb physical disability for these children was 2.6; 4.3 for their lower limb disability. Thus, the overall physical disability of the handicapped group of children who participated in the seriation experiment was 3.4.

4.4.2 Material

4.4.2.1 Real Seriation (Seriation task with wooden sticks)

The sticks used in this part of the experiment have the same dimension as the sticks used by Elkind's standardized version of Piaget's seriation task. Two sets of sticks are used. The A set, with four sticks used for the main seriation task, begins with a 4" stick and the succeeding sticks increase in size by 1/2" increments. Set B, with three sticks used for the insertion task, begins with a 3.3/4" stick and the succeeding sticks increase by 1/2" increments. These sticks have squared shape sections and are made of unpainted wood.

4.4.2.2 Screen Seriation (Seriation task using the computer)

Two sets of sticks are used. The first set has 4 sticks. The first stick is 1.1/4" long and each succeeding stick increases in size by 1/4". This first set is used in the main seriation task. The second set, used for the insertion task, has 3 sticks. The first stick is 1.3/8", the second is 1.7/8", and the third is 2.3/8".

The sticks are displayed on the computer video screen. To manipulate the sticks the subject can use a series of buttons on the computer keyboard that control a cursor. The cursor can be moved to the north, south, east, and west by pushing the buttons which have an arrow pointing in each of these directions. To move a particular stick the subject must move the cursor to that stick until it touches it. At this point, pushing the button labeled GRASP causes the stick to be "grasped." When the stick is grasped, the cursor jumps to the center of the stick. Pushing the directional buttons then moves both the cursor and the stick. The system also includes two buttons for rotation of the sticks. Pressing a rotational button rotates the stick either clockwise or counter-clockwise. When the stick has been moved to the desired place it can be dropped by

pressing another button labeled DROP. The cursor leaves the stick at that particular place and goes back to its original location. Figure 4.2a shows the layout of the initial configuration of the screen, and Figure 4.2b shows the layout of the computer keyboard.

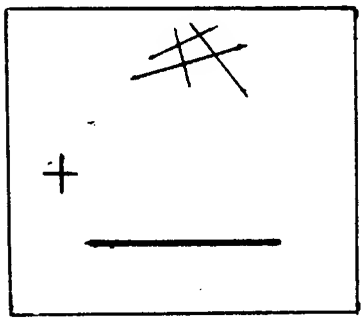

Figure 4.2a

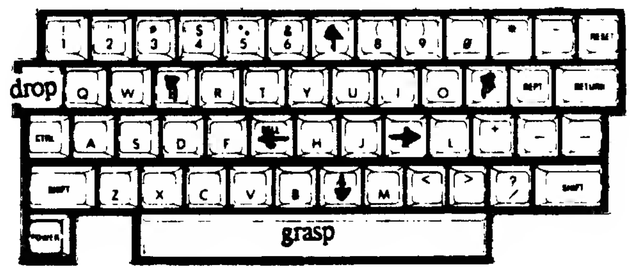

Figure 4.2b

4.4.3 Procedure

The procedure described here was developed based upon the results of the second pilot study, and was used only with the group of cerebral palsied children.

Each cerebral palsied child was tested individually. The real seriation task was administered first, immediately followed by the screen version. Both testing sessions were video-recorded and all the child's moves in the screen seriation were recorded in the automatic recording facility of the system.

4.4.3.1 Real Seriation

This part of the task is divided into two parts: presentation of the seriation goal state pattern, and the construction of the seriation goal state.

The seriation goal state was presented as follows: with a set of four sticks in disarray on the table, I demonstrated the construction of a stairway, with the instruction, "Watch me making a stairway

with these sticks." I constructed the seriation goal state starting with the longest stick and then I selected successive smaller ones until the configuration is finished. This configuration is described to the child as being a stairway. [1]

Construction: A pile of four sticks are presented to the child and he is invited to construct the stairway: "Now it is your turn to make a stairway like the one that I just showed you."

Children who failed to seriate the sticks were not tested further. Those children who were able to seriate the sticks were given three additional sticks and asked to insert them within the stairway. The instruction was, "I have some more sticks that also go in the stairway; can you put them where they belong?" If the child had difficulty understanding the task, the insertion of one stick was demonstrated.

4.4.3.2 Screen Seriation

The screen seriation task was divided into two parts. In the first part the child was introduced to the system, with the objective to allow the child to become familiar with it. Using only two sticks the child had to pick up a stick, orient it straight up, place the stick on the table-top, leave it there and repeat the same procedure for the second stick. The child was allowed to play with the system until he was comfortable with it.

Following this, the proper testing began. I demonstrated a seriated stairway made with four sticks arranged on the table-top, as shown in Figure 4.1a. Then four randomly oriented sticks were displayed on the screen, as shown in Figure 4.2b, and the child was invited to seriate them. If he succeeded three extra sticks were given to be inserted in the series.

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1. Some children were asked to recognize the seriation goal state on a board containing 9 different patterns of 4 sticks. The child was asked to point or to say the number of the pattern that looked like the stairway just seen. After the child's answer, either correct or not, the child was asked to construct the stairway.

4.5 Results

4.5.1 Pilot Studies

The results of both pilot studies showed results similar to those described by other researches who have used the seriation task (Elkind, 1964; Inhelder and Piaget, 1964; Piaget, 1965; Murray and Youniss, 1968).

The results of the first pilot study, involving fourteen normal children, between 5 and 7-years-old, showed that these children did not have any difficulty with the computer version of the seriation task. All fourteen children were able to seriate 6 sticks using the computer. The three 7-year-old children were able to insert three extra sticks. Among the eleven children between the ages of 5 and 6, only five could do insertion. The conclusions of this study were that: (a) children around the age of 7 who are expected to be able to seriate, according to Piaget's findings, could seriate using the computer version of the task; and (b) the computer version of the task had the potential to evaluate children's ability to seriate. In order to investigate this hypothesis, a second pilot study, involving younger children, was arranged.

The second pilot study involved nine normal children between the ages of 4 and 6. They were asked to perform both versions of the seriation task. The results showed that some of these children had difficulty seriating. Among the nine children involved, eight children succeeded in the real seriation, and five succeeded in the screen seriation. Three children, GRE, MAR and ALI (pseudonyms), succeeded in the real seriation but failed in the screen seriation. One child, SAS, failed in both the real and the screen seriations. Table I summarizes the findings and indicates the strategy each child used. These strategies were determined by analyzing the video-tape and the rerun of the screen task.

TABLE I

	GRE	MAR	SAS	AYE	ING	AND	ALI	ALE	VAL
AGE	4.1	4.6	4.7	4.8	4.11	5.0	5.1	5.2	5.7
REAL SER.	Suc.	Suc.	Fail	Suc.	Suc.	Suc.	Suc.	Suc.	Suc.
STRATEGY	Places	Elim.	*	Elim.	Elim.	Inser.	Places	Places	Elim.
SCREEN SER.	Fail	Fail	Fail	Suc.	Suc.	Suc.	Fail	Suc.	Suc.
STRATEGY	Places	Places	Places	Places	Places	Inser.	Places	Inser.	Inser.

* - SAS performed a different task. She constructed a stairway with the sticks not touching the line.

4.5.2 Study with Handicapped Children

Among the 32 cerebral palsied children tested, 20 succeeded in the real seriation, 23 succeeded in the screen version of the task; 17 children could insert extra sticks in the real seriation, and 18 children could insert extra sticks in the screen seriation.[1]

1. Every child who could do insertion in the real seriation did the insertion in the screen version of the task. One child, a 12-year-old girl, could not accomplish insertion in the real seriation but did in the computer version of the task. Table II shows these results.

TABLE II

AGE	11	12	13	14	15	16	17	18	19	TOTAL
NUMBER OF SUBJECTS	3	5	5	3	3	2	5	4	2	32
COULD DO REAL SERIATION	2	4	3	0	2	2	4	2	1	20
COULD DO SCREEN SERIATION	2	4	3	1	2	2	5	2	2	23
COULD DO REAL INSERTION	1	2	3	0	2	2	4	2	1	17
COULD DO SCREEN INSERTION	1	2	3	0	2	2	4	2	1	17
DEGREE OF OVERALL DISABILITY	2	3	3	3	3	3	4	4	4	3.2

Degree of motor disability
1 - no motor impairment
6 - complete impairment of the limb

Three important findings can be drawn from these results. First, the computer helped only 3 children to perform the task. One of these children had hand-motor impairment that prevented him from manipulating the sticks. Thus, it is impossible to evaluate whether his inability to seriate was due to his motor impairment or to the lack of the concepts involved in the real seriation task. The two other children, however, had sufficient hand motor coordination to manipulate the sticks. In the real seriation they adopted strategy of final places, selecting the sticks that were either close to their hand or at the top of the pile. After all the sticks were on the line, they tried to correct the position of the sticks, although they never succeeded. In the screen seriation they adopted strategy of successive elimination, selecting the sticks by size, and placing them to the right of the sticks already in the line. Second, the ability to perform both versions of the seriation task was not significantly correlated with age, as shown in Table III. The Chi Square $x^2 = 0.133$, $p < 0.35$ for the real seriation, and $x^2 = 0.618$, $p < 0.20$ for the screen seriation.

TABLE III

AGE	11 - 14	15 - 19
NUMBER OF SUBJECTS	16	16
COULD DO REAL SERIATION	9	11
COULD DO SCREEN SERIATION	10	13

Third, the ability to perform both versions of the seriation task was not significantly correlated with the motor disabilities of lower and upper limbs combined, as shown in Table IV. The Chi Square $x^2 = 1.963$, $p < 0.20$ for the screen seriation and $x^2 = 1.139$, $p < 0.30$ for the screen seriation. [1]

TABLE IV

	NUMBER OF SUBJECTS	COULD DO REAL SERIATION	COULD DO SCREEN SERIATION
SMALLER THAN 5	8	7	7
BETWEEN 6 AND 7	13	8	9
GREATER THAN 8	11	5	7

4.6 Discussion of the Results

The above results can now be discussed in terms of the three questions that motivated the seriation study: (a) whether the computer system can be a useful assessment tool to be used with physically handicapped individuals; (b) whether age and degree of motor impairment effect the ability of cerebral palsied children to seriate; and (c) whether the strategies used by children with

1. Performance was not significantly correlated with hand (ability to manipulate objects) disabilities -- $p < .30$ for real seriation and $p < .50$ for the screen seriation. Performance was not significantly correlated with lower limb (ability to walk) disabilities -- $p < .20$ for real seriation and $p < .50$ for screen seriation.

cerebral palsy are different from the strategies used by normal children.

4.6.1 Usefulness of the Computer System

The results of the second pilot study showed that three children succeeded in the real seriation but failed in the screen version. This may indicate that the the computer system introduces certain difficulties into manipulating the sticks. However, this should not be interpreted as evidence that the computer is not a useful tool to be used to assess physically handicapped children. Counting the number of children who benefited from the computer system may not be the most appropriate way of evaluating the usefulness of the screen task. A more realistic evaluation might be an analysis of the ways in which the computer system can contribute to the assessment of physically impaired children.

The analysis of the performance of nonhandicapped and cerebral palsied children who succeeded in both tasks indicates that the screen task preserves several features of the real task and it introduces other important features that can be useful to study children's ability to perform a task. For example, the essential aspects of the seriation task are maintained: the child has to discriminate the size of objects, has to identify the relations between sticks, and to use these relations to find the position of a particular stick in the overall configuration. This was shown in the strategies that were used by nonhandicapped and cerebral palsied children -- the strategies adopted to perform the screen task were not different from the strategies that can be used to perform the real task, as described in section 4.3. Thus, the screen task allows the child to solve the the seriation task by using similar strategies he would used to solve the real task.

This indicates that the screen task can be a good assessment tool to be used with children physically handicapped. In the study involving cerebral palsied children, one child, who had a severe hand motor coordination, would not have been able to perform the seriation task without the computer system; other children were able able to perform the real seriation task because they could move the sticks by pushing them around the table. A task that would require different type of manipulation of objects, to construct a tower of blocks, for example, would cause greater

difficulty for handicapped children. In cases such this the computer could be much more useful than it was to perform the seriation task. In addition to being an important assessment tool, the computer system has other desirable features. First, each movement of an object on the screen is discrete which makes easier for the child to focus on particular aspects of the task. The task can be broken into several distinct subtasks, such as grasping a stick, moving it to the table top, and so on. Second, related to the first, stepwise features of the screen task makes easier to observe the strategy the child is adopting. In the case of real seriation, it is common to find children manipulating several sticks at the same time, making it impossible to identify the strategy the child is using to perform the task. The screen task, by emphasizing the intermediary steps of task solution, produces a richness of detail in the child's protocol, facilitating an analysis of the child's intellectual process. For example, the analysis of the cerebral palsied children's performance on the screen seriation task made possible to identify several difficulties these children had in terms of organizing a plan of action and carrying it through. These points will be discussed later. Third, the computer system has the facility to record every movement of objects on the screen, and to use this record to provide a rerun of the task for the purpose of analysis.

It is also important to mention that the screen version of a task introduces other features which may have several implications concerning the degree of difficulty of the task. First, the screen task is two-dimensional. The computer system reduces the number of cues the child can use to discriminate properties of the objects. This can make easier for the child to concentrate on relevant aspects of the task -- for example, the focus is on length rather than other dimensions of the stick. Normal as well as handicapped children had no difficulty discriminating the size of the sticks on the screen. Also, they had no difficulty attributing to the lines on the screen properties of real objects. For example, the line at the bottom of the screen, whose function is to be the "table top", was treated that way. All children referred to it as being the table, and they would not be bothered when the stick would go through the table. Other children treated the sticks on the screen as being real objects. This was observable in the way they maneuvered the cursor or the sticks on the computer screen. As part of the training section I would show that one stick could go

through the others, or that one stick could be on top of another stick; some children, however, moved the sticks so they would not go through other sticks.

Second, among the difficulties of the computer version may be the problem that the children cannot simply reach for the sticks and move them, but has to translate their intentions into instructions for the computer. In fact, the most common problems observed during the performance of the screen task were (a) the coordination of the buttons to move the cursor according to a plan the child had developed, and (b) the use of the system to debug a configuration of sticks. As an example of the first problem, the child would indicate that he wanted the cursor to be at a particular place but would be unable to decide which combination of buttons to use, or the child would move the cursor to a stick to be grasped and would start to move the cursor before "grasping" the stick. These problems did not seem to interfere with the overall performance because as soon as the child had this type of difficulty he would either ask for help or I would ask him to explain his difficulties and then would help to solve them. However, the difficulty in using the system to debug the stick configuration seemed to have interfered with the performance of the two children who were able to perform the real seriation but not the screen version. In the real seriation MAR used the successive elimination strategy, without explicitly comparing the sticks. In the screen task she used the final places strategy. She had very poor placement, and made no attempt to correct the position of the sticks. The reason for ALI's failure in the screen task seemed to be related to the same difficulty that MAR had. ALI used the strategy of final places to perform both versions of the task. In the real seriation she got the sticks in order because she adopted efficient debugging strategies: she switched neighboring sticks and moved sticks to the correct place. However, in the screen task she used neither of these debugging strategies. Instead, she placed sticks on the line to close spatial gaps between sticks, and never corrected their position. A possible explanation for their failure to correct the position of the sticks when using the computer system is that switching sticks in the screen task can be more complicated than in the real task. The child has to remove the stick from the series, and has either to leave it "up in the air," or bring the stick directly to the correct position it belongs. In fact,

neither children used these debugging strategies in the screen task. They might have noticed that to correct the stick configuration they had to do too much work and they did not want to take the trouble to rearrange the sticks.

In addition to these difficulties, the screen task introduces other constraints. In the screen seriation, for example, the length of the table is fixed. This means that the child may not have enough space for arranging the sticks, as in the case of real seriation. Another difficulty is that the movement of the sticks and the positions they can occupy in space is discrete. Some children were uncomfortable with this feature because it produced asymmetric stick configurations. For example, when placing a stick between two other sticks, the third stick may not be equally spaced in relation to the other sticks. Some children kept moving the third stick to find the symmetrical position and had to be told that it was not important to have the sticks equally spaced on the line.

From this analysis we can conclude that the screen version of the seriation task has several features that makes it a different task than the real version of it. In spite of the differences the screen task preserves important features of the task which allow the adoption of the same strategy children use to perform the real task. This makes the screen task a useful tool to study physically handicapped children's ability to perform constructional tasks.

4.6.2 Age and Degree of Motor Impairment and the Capacity to Seriate

The capacity of normal children to seriate is directly proportional to their age. They get better as they get older, and after the age of 7 they can perform the task without any difficulty (Elkind, 1964; Gillieron, 1977; Hood, 1962; Inhelder and Piaget, 1964; Murray and Youniss, 1968; Piaget, 1965; Young, 1973). The same did not happen with the cerebral palsied children. It was not the case that after a certain age all cerebral palsied children were able to seriate the sticks. The results also demonstrated that the degree of motor impairment does not determines success or failure in the seriation task. This means that having more experience did not necessarily improve these children's ability to order a set of four sticks. The fact that these children's capacity to seriate does not develop proportionally to age (or amount of lived experience), however, does not mean that

their cognitive abilities are unalterably diminished. None of the cerebral palsied children adopted a behavior that can be considered different from younger children who are at the pre-seriation stage. Thus, a more appropriate description of their performance is that they are delayed, rather than deviated. However, the delay cannot be generalized to all children. The results of the seriation task, then, do not support Sternlieb's findings that there is 2 to 3 year developmental lag in the acquisition of both space-related and non-space-related operational structures in cerebral palsied children (Sternlieb, 1977). If we divide the cerebral palsied children in the seriation task into three age groups, the percentage of children who were able to seriate is shown in Table V.

TABLE V

AGE	11 - 13	14 - 16	17 - 19
NUMBER OF SUBJECTS	13	8	11
COULD DO REAL SERIATION	69 %	50 %	64 %
COULD DO SCREEN SERIATION	69 %	63 %	81 %

These results do not indicate an across-the-board developmental delay of 2 to 3 years. Some children have reached the second stage at age of 11, indicating a delay of approximately 6 years, while others, at the age of 18, had not yet reached the third stage. There are several explanations for the difference between these and Sternlieb's results. First, cerebral palsied children have, in addition to lack of experience, brain damage affecting several areas of the brain. This implies that we cannot think of these children as subjects who are primarily deprived of sensory-motor experience. Their brain damage must also be considered as an important factor whose effect on their intellectual development is difficult to predict. In addition, there are other aspects to be considered as well. Different cerebral palsied children may have different ways of delaing with their disabilities -- some children could give up trying to think about getting things done, even

though their deficiencies are relatively mild; others may stick to it despite a more serious handicap. These factors may contribute to accentuate the differences among cerebral palsied children's intellectual capacity, which cannot be solely attributed to lack of experience. Second, Sternlieb imposed a limitation on the IQ level of cerebral palsied children who participated in his study. He selected only children with IQ scores above 75. I did not impose this type of constraint in the selection of children. My primarily interest was to work with children who had a severe degree of motor impairment, whose IQ could not be evaluated by the standard methods. Sternlieb's decision implies that he has worked with a group of children who are not representative of the cerebral palsied population. As I mentioned in Chapter 1, 50 percent of cerebral palsied children are considered to have IQ below 70. My decision implies that I may have also worked with a group of children who, in terms of degree of handicapped, are not representative of the cerebral palsied population. In fact, there is a great difference in degree of motor disability between the groups of children in the seriation study and the group of children in Sternlieb's study. According to the these children's Pultibec scores, shown in Table VI, the group of children that participated in my seriation study were more motoricly impaired than those from Sternlieb's group.

TABLE VI

	HAND	**LEG**
STERNLIEB'S SUBJECTS	2.1	3.2
MY SUBJECTS	2.6	4.3

Degree of motor disability
1 - no motor impairment
6 - complete impairment of the limb

Third, the tasks used in both studies were different. Sternlieb used tasks that can be considered multiple-choice, rather than tasks that required the child to construct a pattern. The results of both experiments seem to indicate that the difficulty cerebral palsied children experienced is

related to the ability to solve problems that require the development of a plan of action, the ability to carry it through, and to correct themselves once the plan is leading to a wrong solution to the problem.

4.6.3 Cerebral Palsied Children's Strategies to Seriate

We have seen that to be able to construct the seriation goal state the child needs to coordinate and control several steps required in the execution of the task. The analysis of cerebral palsied children's performance in the seriation task shows that children who failed to seriate presented the following behavior:

(a) As with most normal children between the age of 5 and 6-years-old, the cerebral palsied children selected the sticks either by proximity or randomly, and placed them perpendicular to the table either to the right of the stick furthest to the left on the line (as I did during the demonstration), or filled gaps between sticks.

(b) Contrary to most of the 5 to 6-years-old normal children, the cerebral palsied children would finish placing all the sticks on the line and would not realize that the configuration was wrong. When I would ask them "Is this the same as the stairway I showed to you?", they would say no and would then start to make corrections.

(c) Contrary to the 5 to 6-years-old normal children, the cerebral palsied children adopted very poor debugging techniques -- they would develop a poor plan to correct the order of the sticks. For example, they would keep switching sticks without noticing that their corrections would not lead to the correct stick configuration. In other situations they would change a plan in the middle of its execution and not notice they had done so.

(d) Contrary to what the normal 5 to 6-years-olds would do, the cerebral palsied children would continue repeating actions that were not producing the correct result until they had to be told; this had to be brought to their attention. For example, when they wanted to move the cursor they would push the button to rotate it and would keep doing it without noticing that

the cursor was rotating but not moving.

In the above behaviors it is possible to notice that the main difference between young normal children and the cerebral palsied children who failed in ordering the sticks is lack of control and the inability to organize an effective plan of action. If we assume that cerebral palsied children's intellectual development is delayed, we may conclude that these children have very immature techniques to debug or control a plan of action. It seems as though a cerebral palsied child has the same problem-solving apparatus as the young normal child, with the disadvantage that the latter has learned how to control and debug his techniques, especially when dealing with the real objects. A cerebral palsied children may not have had same opportunities. His problem-solving techniques still need to be developed.

Another explanation is that it is quite possible that some children with cerebral palsy do not have the brain apparatus to support this type of knowledge. They may have massive brain lesions that have damaged large portion of the cortex. However, we must not assume that all cerebral palsied children cannot develop self-monitoring strategies or debugging techniques. There are other means to develop mechanisms that can be useful "crutches." For example, several cerebral palsied children coped with the screen seriation task by talking to themselves about what they should do. They gave themselves directions indicating whether they were wrong or right, and spoke out loud the plan they had adopted. It seems that these children were compensating for some deficiency by relying on their language abilities.[1] This identical technique is utilized by many adults in stressful situations.

4.7 Comparison Between Performances of Four Cerebral Palsied Children

To illustrate the points that I have made so far, I will detail the performance of four cerebral

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1. This behavior was more noticeable during the screen task than on the real version. It seems that the stepwise approach that the computer system introduces to the task facilitates invoking linguistic knowledge, which may be more elaborated than spatial knowledge.

palsied children. These children are approximately the same age, but have different degrees of motor deficiency. Their abilities to seriate were also quite different.

Larry is a quadriplegic boy, 13 years and 8 months old. He is nonvocal and is diagnosed as severe athetoid with some sign of spasticity. He is nonambulatory, and has no use of his hands. His Pultibec score for both lower and upper limbs is 6. He performed both versions of the seriation task by using his head stick. He succeeded in ordering 4 stick and inserting 3 extra sticks in both versions of the task. He used the strategy of successive elimination, selecting the stick by making no direct comparison between sticks.

Liz is a 13 years and 9 months old spastic diplegic girl. She has normal use of her hands, and is able to walk with the help of elbow crutches. Her Pultibec hand score is 1 and her locomotion score is 3. She was not able to succeed in either version of the seriation task. In the real seriation she used the strategy of final places. She selected the sticks that were near to her hands, and placed them to the right of the stick already on the line. She obtained a wrong configuration and made no attempt to correct the order of sticks. In the screen seriation she adopted the same strategy, and, again, obtained the wrong configuration of sticks. When I asked her whether that configuration was correct, she said that she had "messed them up." Her debugging strategy was to switch sticks, although she was not able to correct the order of sticks. At this point she said "I guess it is right. I tried each one. It is hard to remember things." I asked her whether she had difficulty remembering the seriation goal state. She said that that was the reason she could not do it. Then I showed to her a board containing 9 different patterns of 4 sticks, and asked her to point to the pattern she was expected to produce. She pointed to the correct one, and I confirmed that she was correct. She replied, "How come I cannot do it on the machine? Maybe it is because I am not use to it or something.".

Kate is a quadriplegic spastic girl, 14 years and 6 months old. She has reduced motor coordination in both her hands, and is able to walk by using armpit crutches. Her Pultibec score for both lower and upper limbs is 3 (slight loss of motor coordination). She did not succeed in either versions of

the seriation task. In the real seriation she used the strategy of final places, selecting the sticks that were either close to her hands, or on top of the pile. She obtained the wrong configuration, and made no attempt to correct the position of the sticks. In the screen seriation she adopted the strategy of final places, obtained the wrong configuration, and affirmed that was the configuration she should produce. Then I showed to her the seriation goal state again, and she decided that her configuration was incorrect. She made several attempts to correct the order of sticks. In her last attempt she placed one stick on top of the other, and was able to seriate the remaining three sticks. She said that this configuration she said was correct because she had a stairway.

James is a 14 years and 8 months old quadriplegic spastic boy. He is nonambulatory. The motor coordination of his right hand is significantly reduced, and he has no use of his left hand. The Pultibec score for his lower limbs is 6, and for his right hand is 4. He was not able to seriate the real sticks, although he was able succeed in the screen task. In the real seriation he adopted the strategy of final places, and selected the sticks that were closer to his right hand. He obtained a wrong configuration, and made no attempt to correct the position of the sticks. In the screen he adopted the strategy of successive elimination, selecting the sticks with no direct comparison, and was able to order them. However, he was not able to insert the extra sticks correctly.

These different performances demonstrate that the cerebral palsied population is heterogeneous with respect to degree of motor coordination and intellectual capability. Several points are in order. First, the intellectual development of cerebral palsied children cannot be entirely attributed to their lack of experience, as has been suggested in the literature. If this were the case, Larry, who is the most motoricly impaired among these children, should not have been able to succeed in the task; and Liz and Kate, who are less impaired should have been able to succeed. Their performance shows quite the opposite. Thus, there must be other factors that can affect the development of cognitive abilities in cerebral palsied children besides lack of sensory-motor experience. It is our function to provide these children with rich learning experience so we can

begin to sort out whether the absence of certain concepts is due to impoverished experience with the physical world or to the presence of brain lesions. Second, it is not the case that all children approximately the same age have the same ability. This makes it quite difficult to generalize experimental results, as well as to develop educational programs to help these children. It implies that the most appropriate way of studying the intellectual capabilities of cerebral palsied children is by working with each individual, rather than with a large population. Based upon the results of the seriation task I decided to work with few children, and to ask these children to develop activities that could provide them with meaningful learning experience. The activities of each of these children are described in the following three chapters.

4.8 Conclusion

The seriation study allows us to conclude that cerebral palsied capacity to seriate is delayed, rather than deviated. However, this result does not support the theory proposed by Sternlieb which stated that cerebral palsied children's intellectual development is 2 to 3 years delayed, compared to normal children. The results of the seriation task demonstrated that this delay cannot be generalized to all cerebral palsied children, and it is misleading to fix this delay in terms of any other period. Another important conclusion is that the difficulties the cerebral palsied presented cannot be attributed to perceptual disorders. Their performance indicated that these children had a very specific type of difficulty related to their ability to develop a plan, and debugging their strategies and problem solution. This is not a surprise considering that these children have had little experience in solving problems. However, this has not been at all abvious to most investigators, and educators of physically handicapped children.

There are several additional points to be made in relation to the findings of the seriation task. First, it is quite possible that the typical experiences of cerebral palsied children are not sufficient to provide them with the concepts involved in the seriation task. Probably most of these children did not have a chance to engage in problem-solving activities, and they may likely have assumed a very passive role in life -- they may merely acquire factual knowledge rather than have a chance to

both acquire knowledge and to put into practice. The analysis of their performance indicates that the reasons some of these children failed can be attributed to their poor problem-solving skills, rather than an inability to comprehend the key concepts involved in the task. The solution in this case is to provide cerebral palsied children with the opportunity to acquire factual knowledge, as well as the opportunity to apply this knowledge to solution of problems; i.e. giving them a chance to exercise their problem-solving capacity and acquire the ability to develop problem-solving plans, to carry these plans through, to debug mistakes, etc. Second, the fact that these children have brain lesions, certain areas of the brain may be more affected than others. Those children who were not able to seriate, even at the age of 19, may have lesion in areas of the brain that support the development of concepts involved in the seriation task. This means that the development of certain intellectual functions will be limited. However, without the use of appropriate remedial educational programs, it is impossible to affirm whether they will be forever unable to reach higher levels of development. In fact, the work that I developed in the Logo environment with three cerebral palsied children (described in the following chapters) indicated that children who were considered unable to learn certain concepts had a remarkable progress. These children showed signs that they were able to overcome some of the difficulties that were holding them below their true intellectual potential.

Chapter 5

Mike's Case Study: Untrapping the Mind

In this chapter I describe Mike's Logo computer activities. He was 17-years-old when he began working on the LOGO project in October, 1978, and continued his participation until the end of the 1981 school year, when he graduated from high school. Mike's limited motor capabilities have drastically reduced his interaction with the physical world -- there are few things that Mike is able to do. In short, he is a case of trapped intelligence.

During the period he participated in the Logo project Mike used the computer for approximately 10 hours per week. He explored the use of Logo in several areas: drawing, animation, turtle geometry, list processing, business programming, and writing. He produced a massive amount of programming code which filled 27 disks, each disk having the capacity to hold 512,000 characters. The objective of this chapter is threefold. First, to explain, in detail, Mike's development within the Logo environment, and discuss what made it possible. I suggest that what enabled Mike to acquire highly sophisticated programming and problem-solving techniques was a combination of several factors:

(a) his perception of the function of the computer;

(b) the fact that Mike assumed control over his computer work, deciding for himself which activities to develop and how to do them;

(c) his desire for perfection, in terms of having elegant and finished programs that could be both shown to people and used as part of other projects;

(d) his willingness to work out his programming and problem-solving knowledge by defining more general programs, and redefining previous programs in terms of new knowledge that was introduced to him.

Second, to show how Mike's computer activities helped him to acquire skills in domains other than programming, such as writing, mathematics; to improve his motor abilities; and to augment his social interactions with his school colleagues and others around him. Third, to compare Mike's Logo activities with the Logo activities of a younger nonhandicapped child, demonstrating that the solutions they adopted for their problems and programs were quite similar. This suggests that the difference is one of delay, rather than deviation of Mike's problem-solving and programming skills, and that this delay may be at least partially caused by Mike's lack of experiences in solving problems in the physical world.

5.1 Mike's Background

In October, 1978 Mike was 17-years-old, enrolled as a 10th grade student in the Cotting School for Handicapped Children in Boston. Of course, functionally his performance, in some subjects, fell far short of 10th grade work. For example, his writing skills, as shown in section 5.6, were far below 10th grade level. In fact, Mike's true capability remained unknown by the school teachers because his homework was written by his mother.

Mike has severe quadriplegia with some athetoid movements, more marked in the upper limbs, although worse on the right side. He has sufficient motor control in his left upper limbs to control his electric wheelchair, feed himself, type and handle small objects. He is dysarthric, but his speech can be understood when one gets used to it.

Since childhood Mike has been considered to be very bright. At age 5 years 7 months his psychological evaluation indicated that Mike's

> ...mental age is formally about 6 years, I.Q. somewhat above 100 due to well developed language concepts, reasoning and memory skills favored by tests at his present chronological age. The severe deficits of motor ability preclude competitive education, however, and while recognized as intellectually endowed above average he will need very special educational provisions. An allowance must be made for his dependency, social immaturity and emotional explosiveness. This is going to be a very difficult boy to accommodate, probably of above average native mentality but with infuriating communication and motor performance deficits.

When Mike was 12 years and 4 months old the WISC and Peabody/Vocabulary tests were administered to him. Some parts of these tests were impossible for Mike to perform, such as block design and picture arrangement. In cases like this the standard procedure is to extrapolate

from what he could do and to make allowance for the penalizing effects of timing. In this circumstances he was given a verbal IQ of 115 and performance IQ of 96. The comments on this evaluation were: excellent ability to make verbal abstractions despite verbal language problems; excellent reasoning abilities; excellent visual memory; and excellent ability to analyze and synthesize visual impression. Mike's evaluation also mentioned that he had a methodical approach while solving problems, and liked to be challenged with difficult tasks. When Mike was 17 years and 9 months old (8 months after he had started in the computer project), the evaluator noticed that "He [Mike] showed tenacity for all tests, particularly the ones requiring manipulation. It appeared as if he were challenging himself and would not be satisfied until he completed the task to the best of his ability." In addition this evaluation indicated that Mike's weakest areas were in visual discrimination tasks. This was quite surprising because at the computer he had no difficulty reading text on the computer screen. Also, his drawing had a high degree of accuracy. For example, he had no difficulty allocating symmetrical objects on the screen. This is a clear indication that the tests used were presenting results that did not correspond to Mike's true capability. His problem might have been different, but should not have been attributed to poor visual discrimination abilities.

Mike's teachers at the Cotting School observed that speech problems prevented Mike from participating in classroom discussions, and his limited motor coordination made writing and manipulative exercises nearly impossible. These conditions drastically reduced the number of things Mike was able to do and this worried the school staff considerably. Thus, the idea of using the computer sparked Mike's interest. He was so anxious to begin that while the members of the project were deciding whether Mike would be able to use the regular computer keyboard, he went to the computer and developed an ingenious way of typing: he supported his left hand on the frame of the keyboard to inhibit involuntary movements, and pressed the keys with the thumb. Mike was delighted to learn of the existence of a "rub out" key which deletes typing errors. He could see that this one key could make the computer different from any other device he had used before, such as calculators or typewriters.

Mike's computer work revealed two interesting aspects of his cognitive processes. On the one hand, if we consider his degree of motor handicap, it was surprising to discover not only how much knowledge he had acquired, but his creativity, and his commitment to perfection. On the other hand this high degree of competence made it all the more surprising to find situations in which he performed like a small child. For example, Mike's way of approaching a solution of a problem to be implemented in the computer was clearly underdeveloped. His first approach was frequently one of trial and error; an approach often carried to such an extreme point that it was impossible for him to understand what he was doing. In these situations I had to remind him that he already knew, and had used, better techniques to organize his problem-solving tasks. This minor intervention would be enough for him to abandon his hit-or-miss attempts and adopt a "top-down" approach. This same type of intervention was necessary when he was debugging his programs; again, I had to remind him that he should be more systematic. His subsequent actions would show that he knew what I meant.

In the Piagetian computer tasks Mike had no difficulty in seriating the sticks, and in the location of topographical positions[1] he got eight out of nine positions correct. However, in the pseudo-palpation task,[2] his strategy for exploring the screen to find relevant information was very poor. Rather than assimilate the individual pieces of information to form a well-rounded approach he would shift from one possibility to another based on the immediately preceding evidence. Mike's writing skills showed the same problems of disorganization: his sentences were

1. In the localization of topographical positions task the subject is required to localize a "doll" (on a miniature landscape depicted on the screen) in positions corresponding to those the examiner defines by placing the doll on a cardboard relief version of the landscape which has been rotated 180 degrees.

2. In the pseudo-palpation task the subject has to identify a hidden geometrical figure on the screen by manipulating the cursor, which takes two forms: one when it is inside of the boundary of the figure, and another when it is outside. The edge of the figure is detected by noting a change in the shape of the cursor, and a small piece of the edge just crossed can be inspected by pushing the appropriate button. This allows the subject to accumulate evidence as to whether edges are curved, straight, horizontal, oblique, pointed, etc. Exploration of the edges at different parts of hidden geometrical figure can lead to a recognition of the hidden shape. I used the palpation task to test 30 normal children, between the age of 6 to 13 years of age. The results showed that children older than 12 years could recognize all the hidden shapes.

unfinished, and he would jump from one idea to the other ignoring incomplete phrases.

To summarize, Mike became an interesting subject to participate in the research study for two reasons. On one hand, Mike is motivated to learn, he is creative, and has the potential to succeed in the type of learning environment that we have developed. On the other hand, the fact that he is severely physically handicapped and has had a limited experience with the physical world makes him an interesting person to provide with intensive experience in order to explore whether his intellectual disabilities are due to lack of experience or brain lesion. Also, we may explore the question of whether some of his difficulties are due to perceptual dysfunctions, as mentioned in his evaluation, or they are product of underdeveloped cognitive structures.

5.2 Development of Mike's Logo Activities

If we contrast Mike's intellectual potential with his motor and speech disabilities (and, as noted by the psychological evaluators, the difficulties that these impairments generate in terms of providing him with an effective educational environment), there is no question that Mike would be an ideal candidate to participate in a project that is trying to design computer learning environments for physically handicapped children. The reason is quite simple: we would be able to investigate whether the computer can be the communication device that can help Mike to *untrap* his mind. In fact, the computer became an important "tool" serving many functions. It was a working tool with which Mike was able to produce an incredible amount of work, exploring the use of the computer in several areas: writing, drawing, animation, turtle geometry, list processing, and business programming. It was a learning tool through which Mike had a chance to improve his problem-solving and writing skills, as well as learn a great deal about algebra, trigonometry, geometry, number notations, and programming techniques. It was also a social tool through which he had the opportunity to interact with a variety of people; he took great pleasure in showing his work to visitors and introducing Logo to his classmates. Finally, it was a physical therapeutic tool which made possible a noticeable improvement in his motor coordination.

The development of Mike's computer activities took place between October, 1978 and June, 1981. During this period Mike was offered unlimited access to the computer. Twice a week I would come to the school and spend two to three hours per day working with him. Usually he would spend another five hours per week working by himself. During school vacations Mike was brought to the Logo Laboratory at MIT, where he would continue his computer activities. Thus, for almost three years Mike spent approximately 10 hours per week working on the computer.

Mike's Logo activities evolved from simple programs drawing geometrical shapes to programs involving sophisticated programming techniques. His work was very personal and most of the ideas for his projects were quite original. In terms of programming sophistication Mike's computer activities can be divided into three stages. The first stage consisted of programs that were a simple linear sequence of basic Logo commands and equally easy subprocedures which he defined using basic Logo commands. This stage was also marked by an intensive exploration of the computer as a drawing device. The second stage consisted of programs that involve IF and GO TO commands, and ideas which used counters and loops. During this stage Mike started to explore the use of the computer as a device that could carry out some simple tasks and make decisions based upon certain conditions. Finally, in the third stage there were two breakthrough changes. One was in the form of the program. Mike used a large variety of programming techniques including the ideas of recursion,data structure, and algorithms that operate on this data structure. The other change was in the conception of purpose of the computer: it was no longer a toy, but it was seen as tool. In this stage Mike learned to take advantage of the computer as a working tool that could carry out useful tasks. Table I summarizes these three stages, the duration of each stage, and the programs Mike developed in each stage.

TABLE I

STAGE	DURATION	ACTIVITIES
Sequential Programs and Computer as Drawing Instrument	5 months	Geometrical Shapes Animated Car Winter Wonderland Copley Square Alphanumeric Characters
Conditional Programs and Beginning of Utility Programs	5 months	Drawing Text Tic-tac-toe Game Show Computer Note-Book Writing (editor)
Recursive Programs and Computer as Personal Tool	27 months	Big-Show Working Clock Estimate of Costs Writing (editor)

Three important themes emerge as key factors that contribute to the development of Mike's programming skills. The first theme is taking control of his work. This had a great impact because when he could do so he viewed it as his own work, and he took upon himself the responsibility for carrying it through to completion. A second theme is Mike's desire to produce things that are elegant, complete, and display a high degree of creativity and sophistication. This implied that he could accept advice, or a new way of approaching a project. The third theme is his willingness to improve his skills. Mike was willing to polish his programming and to improve the solution of his problem by defining more sophisticated programs, and by redefining previous programs in terms of new knowledge that was introduced to him. These three themes were noticeable in the first stage of his programming activities, and they were consistently present throughout the other two stages.

In the following sections I describe each of the three stages and what accounts for Mike's development.

5.3 The First Stage: Sequential Programs and Computer as a Drawing Intrument

A typical example of programs developed during the first stage of Mike's activities is the procedure TGDS, shown in Figure 5.1a, which draws the background of Copley Square. This procedure is defined in terms of basic Logo commands and subprocedures. The computer produces the picture shown in Figure 5.1b by executing sequentially the commands from line 10 to line 170. This sequential-program style was used in the first five projects that Mike developed: drawing geometrical shapes (turtle geometry), drawing of an animated car, drawing of kinetic patterns ("winter wonderland" picture), drawing of the background of Copley Square, and drawing of alphanumeric characters.

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TO TGDS
10 PENUP
20 BACK 50
30 RIGHT 90
32 FORWARD 25
34 LEFT 90
36 PENDOWN
40 HOUSE
45 RIGHT 90
50 BLL
60 STR
70 RIGHT 180
80 PENUP
90 FORWARD 340
100 RIGHT 90
110 FORWARD 135
120 PENDOWN
130 SS
140 PENUP
150 XYH ( - 22 ) 185 0
160 PENDOWN
170 CSQ 5 10 3
END
```

Figure 5.1a

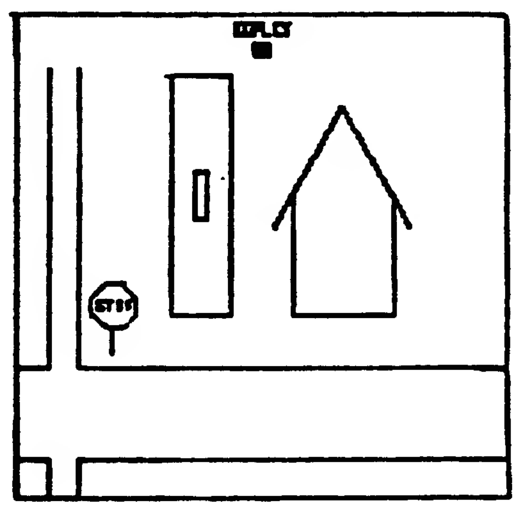


Figure 5.1b

This stage lasted for about five months and was marked by intensive exploration of the computer as a drawing device. Mike had a chance to investigate several drawing features that the computer made available to him. For example, the "winter wonderland" project was the result of Mike's

exploration of the drawing and animation capabilities of Logo. In this project he combined several geometrical shapes, and added the idea of spinning and moving objects on the computer screen, a variation which he discovered entirely on his own. During this stage Mike also had a chance to acquire several programming techniques, and showed a remarkable progress in his programming skills. The projects developed at the end of this stage demonstrate that Mike had mastered the idea of using subprocedures to define more complex procedures. This can be seen when we compare the procedure CAR, the first large project developed at the beginning of computer activities, and the procedure TGDS, one of the last projects he developed in this first stage. The CAR procedure, shown in Figure 5.2a, is a long chain of Logo commands, and does not have subprocedures. The procedure TGDS, the structure of which is shown in Figure 5.2b, uses several subprocedures, especially toward the end of the procedure, where the procedures SS and CSQ are also defined in terms of subprocedures.

```
TO CAR
10 RIGHT 90
20 PENUP
30 FORWARD 150
40 PENDOWN
50 LEFT 90
60 POLYS 45 5
70 LEFT 90
80 FORWARD 300
90 RIGHT 90
100 POLYS 45 5
110 LEFT 90
120 FORWARD 25
130 RIGHT 90
140 FORWARD 50
150 RIGHT 90
160 FORWARD 125
170 LEFT 90
180 FORWARD 25
190 RIGHT 90
200 FORWARD 250
210 RIGHT 90
220 FORWARD 75
230 RIGHT 90
240 FORWARD 50
END
```

Figure 5.2a

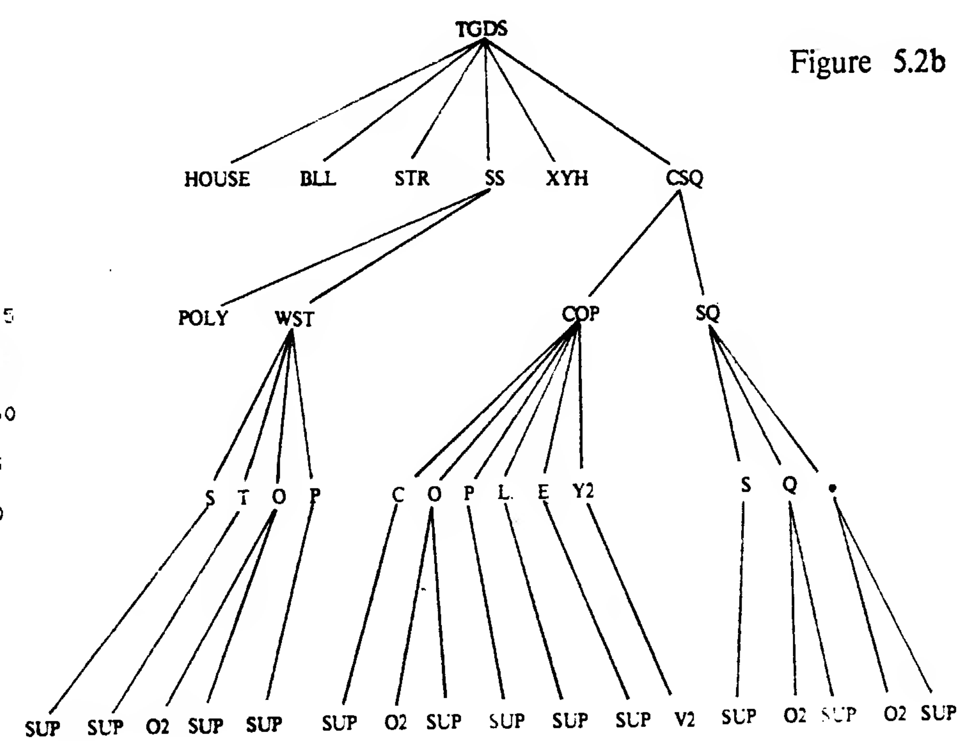


Figure 5.2b

The TGDS project was a good exercise in terms of defining a complex drawing by using subprocedures. After this project Mike had no difficulty in using subprocedures, and always found a way of dividing an overly long procedure into subprocedures. (Sometimes this technique could not be used because the number of subprocedures would grow out of proportion and the computer memory was not large enough to store them all.) Besides this improvement in his problem-solving skills, Mike had also the opportunity to learn several other skills such as algebra and trigonometry, as I will show later. The question, then, is "what made this skills improvement possible -- how did it happen?"

5.3.1 Assuming Control

In this first stage there were several incidents that helped to establish Mike's programming style, his "ways-of-working" which were used throughout his computer activities. The first incident occurred when he assumed control over his activities: Mike refused to continue a project of drawing geometrical shapes that I had suggested as his first computer activity. This project was focused around the "Total Turtle Trip Theorem" (Abelson and diSessa, 1981), and my decision to begin with it was based on research accumulated over several years that shows that most high school students enjoy doing turtle geometry. Once the basic ideas are mastered many students find it interesting to explore the different types of polygons and stars that can be drawn by varying the angle and the length of the sides. Also, it is an appropriate project to use to introduce the ideas of angle, recursion, and operation with simple procedures.

Although Mike did not have problems grasping the essential ideas in this project, he took little initiative in exploring different ways of using the procedures he defined. Almost everything was done because of my requests. Finally, one day he got very frustrated, showed disappointment in his performance with the computer, and left in the middle of the session.

There are several possible reasons that may explain Mike's behavior: too many new concepts at once; he did not control the learning situation; he had not thought of using the computer to do "math" but rather to have fun. I believe that, to a certain extent, all these factors contributed to

his frustration. However, it is my conviction that the factor that contributed most significantly to his growing frustration was the fact that the decision to do turtle geometry was not initiated by Mike. This placed him in the position that he had been in all his life -- not being able to initiate or do things on his own. The fact that he did not know some of the concepts involved in this activity seems to have played a less important role since later he had no difficulty applying these concepts in activities that he had initiated on his own. (The CAR, the "winter wonderland," and the background of Copley Square, all involved turtle geometry.)

This episode helped us to establish a working relationship in which we switched roles regarding whom should be in charge of Mike's computer activities. He assumed a more active role, deciding what he wanted to do and how to do it; my function was to keep his activities rich and interesting enough to facilitate the development of his programming and problem-solving skills.

5.3.2 Willingness to Improve

From the beginning of our work together Mike showed a fervent desire to improve his ideas and acquire more sophisticated programming techniques. This helped to develop a productive working relationship -- I knew that I could intervene in his work and make suggestions which Mike would or would not take depending upon whether the suggestion met his needs. For example, the idea of defining shorter programs was very appealing to him since it made his programs much easier to understand and to debug. Mike had no problem accepting this idea. I used the procedure CAR to introduce to Mike the problem-solving heuristic of breaking a problem into subproblems. By using this approach he could define subprocedures for each subproblem, and then use these subprocedures to define a superprocedure which would solve the original problem. Since the new procedure became much simpler I used it again to introduce the concept of variable, so the size of the car could be changed. The superprocedure and the subprocedures, using variables, for drawing the car are shown in Figure 5.3.

```
TO BX :X :Y
20 FORWARD :X
30 RIGHT 90
40 FORWARD :Y
50 RIGHT 90
60 FORWARD :X
END
```

```
TO NCAR :X :Y
10 LEFT 90
20 BX :X :Y
30 LEFT 90
40 FORWARD :Y
50 RIGHT 90
60 BX 2 * :X 2 * :Y
70 BW :X
80 FW :X
END
```

```
TO FW :X
10 LEFT 90
20 PENUP
30 FORWARD 2 * :X
40 RIGHT 90
50 PENDOWN
60 RCIRCLE :X / 4.
END
```

```
TO BW :X
10 PENUP
20 BACK 4 * :X / 3.
30 RIGHT 90
40 PENDOWN
50 RCIRCLE :X / 4.
END
```

Figure 5.3

Thus, Mike's willingness to learn new programming techniques and his willingness to use these methods to redefine previous procedures made it possible for me to introduce several new Logo commands and, in addition, the idea that there is more than one solution to a problem. This was extremely important for the development of his programming and problem-solving skills. The process of redefining a procedure was a technique that Mike had no problem dealing with and he used it throughout his computer work. He even developed a systematic way of keeping the old procedure by naming it with its original name prefixed by the letter O (for old).

5.3.3 Desire for Elegance

Another factor that contributed to the development of Mike's programming skills was his systematic definition of more general and powerful procedures that were more elegant from the point of view of programming and efficiency, including possible reuse in other projects. This desire for elegance and perfection was parallel to the idea of having control, and it created the possibility for aesthetic expression. As a person who has been deprived of opportunities for expressing his intellectual potential it seemed quite natural for him to want to take advantage of his computer work as a way of showing-off.

I encouraged this approach throughout Mike's work and, again, he had no difficulty accepting this idea. A good example of this was a project to define procedures to draw the letters of the alphabet. This project came about because Mike needed to define some procedures to draw words in the background of his Copley Square project -- the word STOP on the stop sign. This gave him the idea of defining procedures to draw all the letters, the numbers, and a few other characters. Moreover, he could use these procedures to draw alphanumeric characters with variable size. This created an interesting situation. To draw these letters he would need to know concepts of algebra and trigonometry, which he did not hesitate to learn. This helped him to reach his goals, to make his project more challenging, and demonstrated his creative capacity.

To draw letters of the alphabet with variable size, we decided to draw each letter inside an invisible rectangular frame where height and width can be adjusted. By making the parts of the letter a function of these two variables, the size of the letter can be changed by giving different values to them. For example, to draw the letter G, the rectangular frame is defined as having height Y and width X (Figure 5.4a). Inside of this frame we can draw the letter G where the parts of it can be defined as shown in Figure 5.4b. Therefore, the procedure to draw the letter G has two variables, X and Y (as size of the frame), and a variable L which indicates the distance between two letters. The procedure is shown in Figure 5.4c.

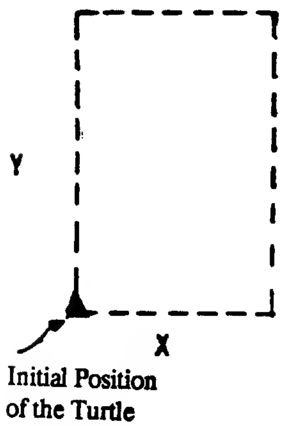


Figure 5.4a

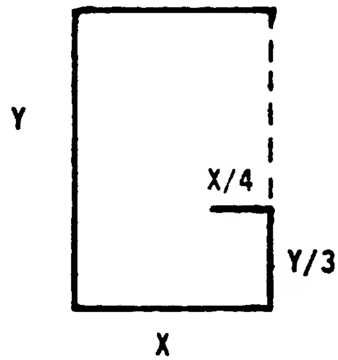


Figure 5.4b

```
TO G :X :Y :L
10 PENUP
20 FORWARD :Y
30 RIGHT 90
40 FORWARD :X
50 PENDOWN
60 RIGHT 180
70 FORWARD :X
80 LEFT 90
90 FORWARD :Y
100 LEFT 90
110 FORWARD :X
120 LEFT 90
130 FORWARD :Y / 3
135 LEFT 90
140 PENUP
150 FORWARD :X / 4
160 PENDOWN
170 RIGHT 180
180 FORWARD :X / 4
190 SUF :L :Y / 3
200 HIDETURTLE
END
```

Figure 5.4c

It is relatively straightforward to define procedures for those letters which can be drawn using only horizontal and vertical lines -- e.g., L, T, E -- and Mike very rapidly mastered this. When the letter has slopes -- e.g., R and K -- things are not quite as easy. The angle of the slope and its size change in relation to the size of the frame. For example:

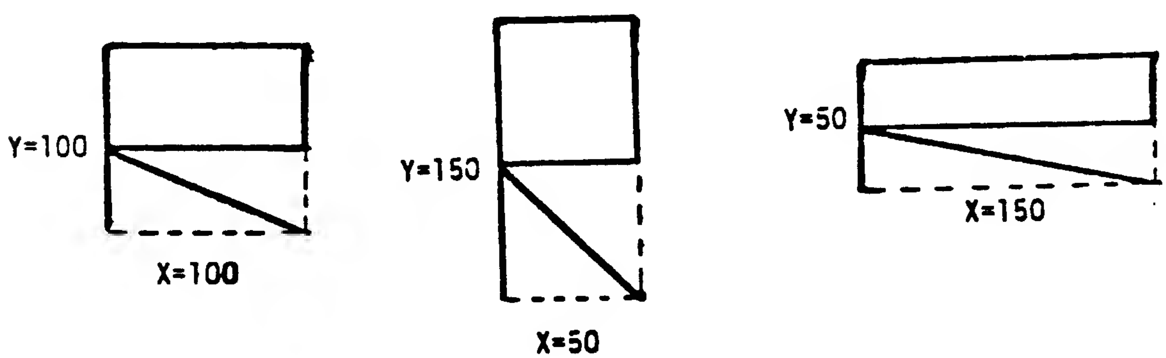


Figure 5.5

This provided the opportunity to introduce Mike to the basic notions of practical trigonometry and to state invariant turtle procedures. This latter feature facilitates the use of procedures in other projects since the orientation of the turtle does not change after a letter or a number is drawn. The Logo terminology for this is "making the state of the turtle transparent"; that is, if the turtle starts a procedure facing up it will end facing up after the procedure has been executed. The position of the turtle is set by the third argument of the procedure. These letter drawing procedures are used in several projects: drawing sentences on the computer screen, numbering the slots of the tic-tac-toe board, numbering the face of the clock, and drawing the words "WELCOME TO LOGO" in BIG.SHOW.

Thus, by assuming control over his activities, by defining more general procedures and by redefining procedures and ideas for projects, Mike acquired new Logo commands and concepts, and had a chance to exercise his knowledge by doing things in more than one way. This working style was established in this first stage and was maintained throughout the other two stages.

5.4 The Second Stage: Conditional Programs and Beginning of Utility Programs

The theme of control was powerful in developing Mike's success, but also held him back, delaying transition to the second stage. First he had to "work through" his need to assume control of his activities. Programs undertaken during the second stage had a different function than the programs in the first stage. In the second stage Mike started to explore the potential of the computer as a device that can make decisions based upon certain conditions. This introduced the idea of conditionals, such as the IF and the GO commands. With these commands it was possible to define algorithms (in which a set of commands were repeated in a loop a certain number of times controlled by a counter) to solve more elaborate problems. These programs were not sequential, as were the programs of the first stage, but the order of command execution depended upon certain conditions.

The transition from the first category of programs to the second took place when Mike started testing his procedures to draw alphanumeric characters. He would test them by drawing words on

the screen. This gave him the idea of using these procedures to write sentences, or anything else that people would ask for. He also thought this program would be useful to help some of the Cotting students who had visual problems; using a large size for the letters visually-impaired people would be able to read and eventually use the computer.

To develop the program to write words on the screen Mike needed the notion of comparison between values, as in the procedure LGR, shown in Figure 5.6. This procedure accepts a name of a letter as input (variable :M), identifies it, and calls the procedure to draw the respective letter on the screen.

```
TO LGR :M :X :Y :L
10 IF :M = "A A :X :Y :L
20 IF :M = "B B :X :Y :L
30 IF :M = "C C :X :Y :L
40 IF :M = "D D :X :Y :L
50 IF :M = "E E :X :Y :L
60 IF :M = "F F. :X :Y :L
70 IF :M = "G G :X :Y :L
80 IF :M = "H H. :X :Y :L
90 IF :M = "I I :X :Y :L
100 IF :M = "J J :X :Y :L
110 IF :M = "K K :X :Y :L
120 IF :M = "L L. :X :Y :L
130 IF :M = "M M :X :Y :L
140 IF :M = "N N :X :Y :L
150 IF :M = "O O :X :Y :L
160 IF :M = "P P :X :Y :L
170 IF :M = "Q Q :X :Y :L
180 IF :M = "R R :X :Y :L
190 IF :M = "S S :X :Y :L
200 IF :M = "T T :X :Y :L
210 IF :M = "U U :X :Y :L
220 IF :M = "V V :X :Y :L
230 IF :M = "W W :X :Y :L
240 IF :M = "X X :X :Y :L
250 IF :M = "Y Y :X :Y :L
260 IF :M = "Z Z :X :Y :L
270 IF :M = "^[ ^[ :X :Y :L
280 IF :M = ". . :X :Y :L
END
```

Figure 5.6

Mike also used the concept of conditionals to develop a program to play tic-tac-toe. This was a simplified version of a project he had planned in which the computer would be able to play the game against another person. Considering the difficulty in implementing this project, I suggested that he should define a program that would keep the status of the game and the score. The computer, in this version of the game, would function as pencil and paper. The fact that the computer could make decisions, and could carry out such activities as keeping score, had a significant impact on Mike's way of understanding the potential of the computer. During this stage he started to use the computer to keep a notebook with the names of all the files and procedures he had defined. He also started using the computer text-editor to produce writing, which he had never done before.

Thus, in the second stage, which lasted for about 5 months, there was a shift in Mike's view of how to use the computer, which effected both his programming style and his way of using the computer. The computer became more like a aide, doing things that Mike could not otherwise do because of his motor disabilities. However, he kept his original style. He had control over what to do, and he continued to redefine procedures so the old ones would incorporate new ideas. For example, the board of the tic-tac-toe game, procedure OTTTB (Old Tic-Tac-Toe Board, shown in Figure 5.7a) was initially defined by using only Logo commands. Yet, Mike experienced considerable difficulty adjusting the position of the turtle so that the slots in the board would come out perfectly squared. After he finished he saw that this could be more easily accomplished and that the procedure would be much more elegant by using the idea of Cartesian coordinates. He used the procedure XYH, which he had defined while developing the Copley Square project. This procedure sets up the turtle at coordinates X and Y and sets the turtle heading with angle H. By using this procedure he redefined procedure OTTTB and produced procedure TTTB as shown in Figure 5.7b.

```
TO OTTTB
10 PENUP
20 LEFT 90
30 FORWARD 200
40 RIGHT 90
50 FORWARD 200
60 RIGHT 90
70 FORWARD 133
80 PENDOWN
90 RIGHT 90
100 FORWARD 400
110 PENUP
120 LEFT 90
130 FORWARD 133
140 PENDOWN
150 LEFT 90
160 FORWARD 400
170 PENUP
180 RIGHT 90
190 FORWARD 133
200 RIGHT 90
210 FORWARD 133
220 PENDOWN
230 RIGHT 90
240 FORWARD 375
250 PENUP
260 LEFT 90
270 FORWARD 133
280 PENDOWN
290 LEFT 90
300 FORWARD 375
310 PENUP
320 HOME
END
```

Figure 5.7a

```
TO XYH :X :Y :H
10 PENUP
20 SETXY :X :Y
30 SETHEADING :H
40 PENDOWN
END
```

```
TO TTTB
10 PENUP
20 XYH ( - 75 ) 200 180
30 PENDOWN
40 FORWARD 400
50 PENUP
60 XYH 70 ( - 200 ) 0
70 PENDOWN
80 FORWARD 400
90 PENUP
100 XYH 200 70 270
110 PENDOWN
120 FORWARD 400
130 PENUP
140 XYH ( - 200 ) ( - 70 ) 90
150 PENDOWN
160 FORWARD 400
170 PENUP
180 XYH 0 0 0
200 HIDETURTLE
END
```

Figure 5.7b

Since Mike had learned that the computer could make decisions and carry out work, he used this new information to define SHOW, a procedure to display the "winter wonderland" kinetic pattern and to demonstrate its construction through simple steps of successive graphic complexity. This program was developed because, in Mike's demonstrations of his computer work, observers did not have the patience to wait for him to type the name of the procedures to be executed. Thus, the procedure SHOW was developed to eliminate typing. It shows the sequence of pictures by simply hitting the spacebar on the computer keyboard. When a picture in the sequence has been shown, a HALT procedure makes the computer wait to show another picture until the spacebar is hit.

SHOW was useful procedure in several ways. First, it fulfilled an important function for Mike since it made it possible for him to get more things done with less effort. Second, it combined programming styles from both the first and the second stages: linearity and the use of the IF command to decide when to continue the execution of the procedure. Third, it was a bridge between the second and the third stages. I used the SHOW procedure to introduce Mike to the idea of lists and the commands to operate with lists. He redefined SHOW in terms of these new concepts. The previous procedure SHOW was renamed OSHOW, shown in Figure 5.8a, and the procedure that incorporated the new ideas was named SHOW, and it is shown in Figure 5.8b.

```
TO OSHOW
5 CLEARSCREEN
10 DT
20 PRINT [2M.SPS4.6]
30 2M.SPS4.6
40 HALT
50 CLEARSCREEN
60 PRINT [SQUARE]
70 SQUARE
80 HALT
90 CLEARSCREEN
100 PRINT [PEN]
110 PEN
120 HALT
130 CLEARSCREEN
140 PRINT [S.P.S]
150 S.P.S
160 HALT
170 CLEARSCREEN
180 PRINT [S.P.S4]
190 S.P.S4
200 HALT
210 CLEARSCREEN
220 PRINT [M.S.P.S4]
230 M.S.P.S4
240 HALT
250 CLEARSCREEN
260 PRINT [2M.S.P.S4]
270 2M.S.P.S4
280 HALT
290 CLEARSCREEN
300 PRINT [2M.SPS4.6]
310 2M.SPS4.6
320 DT
END
```

Figure 5.8a

```
TO SHOW
5 CD
10 MAKE "LIST [2M.SPS4.6 SQUARE PEN S.P.S
S.P.S4 M.S.P.S4 2M.S.P.S4 2M.SPS4.6]
15 DT
18 PRINT "
20 IF :LIST = [] DT STOP
30 MAKE "PROG FIRST :LIST
40 CLEARSCREEN
50 PRINT :PROG
60 RUN SENTENCE [] :PROG
62 PRINT "
65 PRINT [IT IS ALL FINISHED]
67 PRINT "
70 HALT
80 MAKE "LIST BUTFIRST :LIST
90 GO 20
END
```

Figure 5.8b

Both procedures produce the same results, although the new SHOW incorporates the concept of data representation by using a list as a data structure (line 10) and the idea of an algorithm operating on this data structure. This constituted the transition to the third stage in Mike's programming style.

5.5 The Third Stage: Recursive Programs and the Computer as a Personal Tool

Mike's third stage is marked by two aspects. First, he learned to take full advantage of the computer as a tool. The computer could carry out clever and useful jobs, such as the BIG-SHOW

and the ESTIMATE programs, and could be used to produce writing and aid his English exercises. A good example of Mike's view of the computer as a tool is the ESTIMATE program, which was developed because Mike wanted to make available, to the manager of the printing department of Cotting School, a program that would estimate the cost of jobs requested by customers of the printing department. Also, Mike thought that this program would be a good exercise in using the computer to do practical things other than drawings, which if he were to work as a programmer he needed to know. Thus, the computer became part of Mike's career plans and it could be his way in the working market. Second, Mike's program is marked by more sophisticated programming concepts including recursion, loops, and list and array data structures. Three projects were developed using these ideas: BIG.SHOW, which shows all Mike's computer work; CLOCK, which draws a face of a clock and moves arms controlled by the internal computer timer; and ESTIMATE. The ESTIMATE project was Mike's last, and it involves several types of data structures; for example lists to keep sizes of several types of paper; arrays to store the cost of each item that enters into the production of a job; and algorithms to minimize paper wastage, to round-out numbers with decimals so they can have only two digits, and to format the printout statements so the costs of the items are aligned in columns.

The computer gave to Mike a way of moving beyond the limits imposed by his disabilities, and he took a great pleasure in showing what he could produce. This positive, affective reaction was noticeable, for example, when he started developing the program BIG.SHOW, which would display all of his computer work using minimal typing effort. Initially BIG.SHOW greets the visitor by drawing several small squares starting at the center of the display and moving apart from each other, representing the big bang. Then, in the background, the words WELCOME TO LOGO start to appear. By pushing the space bar BIG.SHOW asks for the visitor's name and then presents a "menu" of projects the visitor can choose from by typing the corresponding number. The procedures from that project are loaded into the computer memory and the particular procedure that draws the requested product of that project is executed. Once the drawing is completed BIG.SHOW, using the visitor's name, asks if he/she wants to see something else

pertaining to that project; e.g., a printout or the execution of a particular procedure. If the visitor is satisfied, all the procedures from that project are erased and the control goes back to the procedure that prints the "menu." The structure of this program is shown in Figure 5.9.

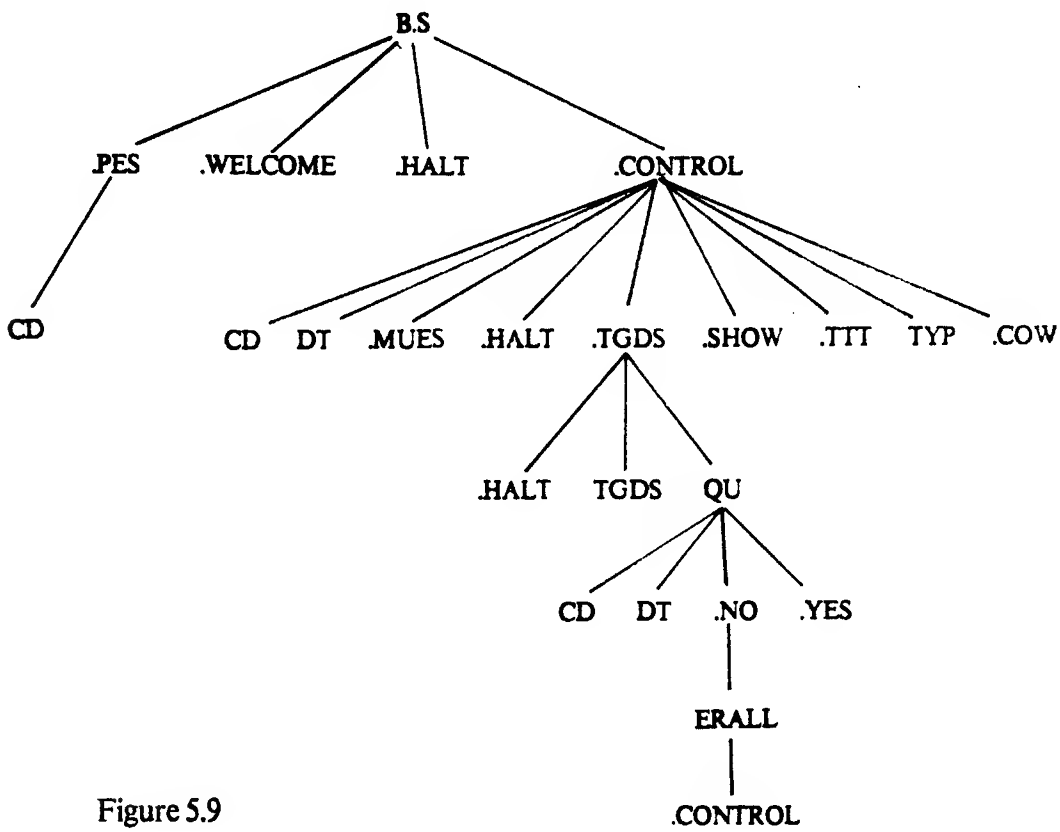


Figure 5.9

For each project that Mike showed using the BIG.SHOW program, he had a story to tell to the visitors in order to capture their attention and to make his performance more enjoyable. Setting up and performing shows, of course, were not the goals of Mike's computer activities. In general all Logo users like to show off their work. What is important is that Mike developed interesting things to show to people, and in doing so he created additional problems which, in turn, forced him to enhance his academic skills and to learn even more about programming. An example is the development of the BIG.SHOW program. The original thought was to extend the concepts used in the SHOW program. However, when Mike transferred the approach he used in SHOW to define a new procedure to display all of his projects, it did not work. The sum total of

procedures in all the projects was too large and the computer did not have the memory capacity to allow them to be executed. Thus, Mike could not use the same ideas he used to develop the SHOW procedure, and his approach for BIG.SHOW had to be reconsidered. Mike adopted the solution of keeping only those procedures from BIG.SHOW and the procedures from the project being currently displayed in the computer memory. When another project was chosen, the procedures of the previous project were erased. To implement this solution Mike had to solve several problems: to present the "menu" of projects from which the visitor can choose a project; to design a procedure that controls the execution of other procedures; and to distinguish the procedures that have to be erased from those that have to be left in the memory. The development of the BIG.SHOW project was the first time that Mike had to face the problem of computer memory limitation. The solution he adopted was transferred to other large projects, such as ESTIMATE.

Thus, Mike's Logo activities emerged as a blend of several factors: a working relationship where he established control of his computer work; his interest in producing projects to express his intellectual abilities; his willingness to define general procedures so they could be used in other projects; and his willingness to elaborate his programming techniques and ideas by redefining old procedures in terms of new knowledge. In this way Mike was able to reach higher levels of sophistication in his programs and problem-solving techniques, as well as acquire skills in academic domains other than programming.

5.6 Improvement in Writing Skills

Another area in which Mike has achieved remarkable improvement is writing. Since he always depended upon other people to write for him, Mike lacked experience. In May, 1979 Mike started to keep a notebook in the computer. This notebook contained the names of all his files and their corresponding procedures. This was the first time Mike produced written material with the computer. During the summer of that same year, Mike was brought to the Logo Laboratory at MIT where I made a text-editor available to him so he could write essays about his experience in

Logo. The following is Mike's first written output:

> "I ment Dr. Sileva Where, Jose Valente and Gary Drescher on October 5, 1978 at 9 : 32 : 47 AM. which the compuer I was so excized it like being it a waitting & maternace room at a hospital whiting to fine it oot's a boy or a grail.
>
> We had A and we whont you to do it fist for us I am Logo number "1" ginny pig. When they get a new idse they say to hel, Michalel we had A and we whont you to do it fist for us
>
> Like a nice guy I do if I wont to or not. I do and then I give my por and con on the idse. I tell them why I came up for a allturative. Why you mite ask? Becose I know how the person on the arther end feel Becose I am the middle man beteew M.I.T and handcap people
>
> I am a teacher of five standt. Wild I was teaching I lean that no two poeple lean at the same rate. When I teach I lean form my standt. As well or bedter then form a book. I call that on the job training. My fist and every day experreance with the compuer when it cash and it lost but it keep on losting all that I have tort it but keep no teaching it overy and overy agian when I bring back to live."

Several interesting points emerge from this text. First, this writing looks like "spoken English" rather than "written English." Second, it contains systematic errors which are very common among cerebral palsied children; for example, letters are reversed, "por" for "pro," "poeple" for "people" (Cruickshank, 1976a). There are also some difficulties with certain spoken words such as "standt" or "stundt" for "student," "tort" for "taught" -- which are, again, characteristic patterns of language deficiencies found in cerebral palsied children (Cohen and Hannigan, 1956). Third, patterns in Mike's writing suggest the same language deficiencies that are found in aphasic patients, especially Broca's aphasia. This is characterized by a disturbance of the mechanisms that underlie the ability to structure sequence of words syntactically; inflectional marks for plurals, possessives, and third person singular /s/ are affected differentially (Caramazzo and Berndt, 1978). In his writing we notice errors of tense: "feel" for "feels," "handicap" for "handicapped," "take" for "takes," "keep" for "kept." Also, several words are omitted, particularly those that concatenate ideas, such as "I was so excised [that] it [was] like being," or omission of letters in words, e.g. the "r"s coming before consonants, as in "fist" for "first," "lean" for "learn," which are common in written prose of Broca's aphasic patients (Goodgrass and Geschwind, 1976).

On the other hand, Mike's writing also shows several mistakes that may be due to lack of writing experience. For example, there are several errors that may be attributed to simple spelling mistakes -- such as "waitting" for "waiting," or "becose" for "because" -- or with sounds articulated at the front of the mouth (involving dentals), such as "compuer" for "computer," "excized" for "excited." Mike attributed these errors to the common problem that his "mind goes faster than his hand"; that is while he is typing one word he is thinking about the next one. I also noticed that after finishing a sentence Mike never rechecked it for mistakes. When he did, he would say aloud what the sentence should be, instead of reading what he had written. Thus, Mike might actually know more English than what the strict analysis of this text indicates. Ultimately, what Mike needed was to gain experience and discipline in writing, skills he had never acquired because he had never written in his life.

To provide him with this experience, a remedial writing program was set up and an English teacher worked with him. This program began in January, 1980, and Mike was involved in it until the end of the project, in June, 1981. Mike wrote as much he could using the computer text-editor. In addition, his English teacher gave him exercises based on weaknesses shown in his writing sample. These exercises consisted of writing composite sentences, forming negative and interrogative sentences from those in the affirmative, forming passive sentences from active ones, and vice-versa. He also had to write book reviews, essays, and letters to friends and business companies. All of his lessons took place in the computer room, and he had to produce all the written material typing by himself at the keyboard -- no longer did someone else write for him. Mike's progress was remarkable, and it was possible to notice a gradual improvement in his writing skills. In February, 1981 he wrote a letter to another cerebral palsied person who was interested to learn about Mike's computer activities (published in Weir, 1981). In this letter Mike made very few mistakes and the structure of his sentences indicates a remarkable improvement.

A similar remedial program was setup at the University of Massachusetts, where Mike is continuing his academic work. His first-year English teacher emphasized the organization of

ideas, and how to structure required papers. Mike had to write about different subjects, including subjects of his choice. His teacher would give him feedback and, if necessary, she would require him to rewrite the paper until she was satisfied with it. The following essay is the final paper Mike wrote in that course.

Trapped Intelligence

Trapped intelligence is a phrase which is used to describe people who have normal or above normal intelligence but are non-verbal or slow talking and society assumes that these people are stupid. Project Logo and the computer have changed this meaning. It has allowed people to show what they can contribute to society.

For the first nine years of my schooling, I was at the Cotting School for the Handicapped and nobody knew what my potenial was or would be. There was evidence that I was capable of doing the work but how much more was the puzzeling part. Several tests were taken each only measuring a certain areas of intelligence.

At this time M.I.T. (Massachusetts Institute of Technology) approached the faculty of the Cotting School with a new concept of communication. The project was called "LOGO". Logo is a computer language which is used as a diagnostic tool allowing non-verbal people to show their potential. The school accepted their offer to come only under one condition, that being, that they have Michael Murphy as their first recuit. Having a candidate, they now proceeded to experiment with the machine and me. They assigned one professor to work with me, (Jose Valiente). We worked very closely together and on different projects. Through the machine we found that we could solve almost any problem.

After six months of working with the program the faculty and some of the other students kept questioning me about what the computer could do, so we started a small class to answer some of these questions with me as the teacher and Jose as the advisor.

Through our association with M.I.T. and the students at the Cotting School a scientific break-through had taken place. A tool by which people with severe handicapped could communicate and be useful to the outside world. This break-through excited many people in the Medical and Scientific fields. Local news media contacted the School to see for themselves what was happening.

Karen Ray from M.I.T. wrote an article about the program and Project Logo which was picked up by a national magizine (Science 80). From that one article the School recieved many inquires about this new idea. One of them was from a local T.V. program called "Eveing Magizine". The presented it on a medical segment on Nov.6 1980.

Enthusiasm and responses were coming in from all over the country, Brazil and Canada. wanting all information relating to "Logo". Another one of these was from the producers of "Thats Incredible" a national program which shows new break-throughs in different scientific and medical areas.

> With the help of some publicity the Cotting School now has a full computer science center, preparing and teaching other students who are interested in working in the computer field.
>
> Trapped intelligence may be trapped for a short period of time but now with the aid of such projects as "LOGO" new avenues of communication and education have been opened.

This paper did not need any revisions. The teacher's comments were "some spelling mistakes - magazine, received, puzzling, etc - but content and organization are excellent. Oh,yes, one sentence fragment - can you find it?" It is clear that there has been a great improvement in Mike's writing skills, and it has been an activity he has enjoyed doing.

5.7 Improvement in Motor Abilities

Mike's computer activities are also responsible for significant improvement in the motor coordination of his left hand and right arm. As I mentioned previously, no special typing device was needed to compensate for Mike's physical impairment. Because he developed an ingenious way of typing he could use the regular computer keyboard. To inhibit involuntary movements he supported his left hand on the casing which surrounds the keyboard and pressed the keys with his thumb. Although this helped him to overcome some of his typing difficulties, his motor impairment still slowed his typing performance. During the first Logo sessions Mike could type an average of 440 characters in 50 minutes, or approximately 9 characters per minute.[1] His most frequent mistake was to accidently type a letter that was close to the one he wanted. For example, instead of the letter F, for the FD command, he would type D or G; or he would type double letters because the uncontrollable movements of his thumb would type the same key twice and he would not notice it.

Due to his intensive work with the computer, there was a remarkable improvement in the motor

1. In the beginning of Mike's work, each session would be of about 50 minutes. In the first session he typed 449 characters, in the second session he typed 455, third session 434, and fourth session 431.

coordination of his left hand. His typing skills improved a great deal after eight months in the project; by June, 1979 he was typing an average of 23 characters per minute,[1] and his average number of mistakes also decreased. In the four sessions that I used to evaluate his typing skills there were only three typos; in two of them he did not type a space between two commands, and in the other he typed a space between the letters of a word. This means that he was much more aware of his mistakes and could correct them by using the "delete" key.

During the initial period of Mike's computer work he could not type two keys at the same time; that is, he could neither hold the "control" key down and simultaneously type the the letter G to stop the computer, nor hold the "shift" key and strike another key. In this case I had to hold one key and he would type the other key. In our sixth session Mike asked for a heavy object to hold down either the "control" or the "shift" keys when necessary so that he would not need another person to do so. This object was a small sized brick that Mike asked the people from the printing shop to build for him. By the beginning of February, 1979 Mike started using the index and middle fingers of his left hand: he would hold the "control" or the "shift" key with his middle finger and would type the second key with his index finger. For the keys beyond the reach of these two fingers of his left hand he continued using the brick. Around April, 1980 Mike started to use the index finger of his right hand to hold either the "control" or the "shift" keys and type the second key with the thumb of the left hand. This last method was a major achievement because Mike had previously been unable to used his right limb for performing tasks that required fine motor coordination.

While it is impossible to prove that his hand coordination would not have improved in the absence of his Logo experiences it seems clear that Mike had sufficient motivation to work on his

1. In a 30 minute session on May 17 Mike typed 684 characters (22 characters per minute); on May 31 he typed 668 characters in 35 minutes (19 per minute); on June 7th he typed 200 characters in 7 minutes (28 per minute); and on June 8th he typed 415 characters in 18 minutes (23 per minute). These dates were selected because around this time I introduced into his "login" command a feature that would print in the "dribble" file the date and time Mike started his computer session.

coordination problems so he could increase the speed by which his projects could be accomplished.

5.8 Development of Social Interaction

The development of Mike's computer skills had a great impact on his attitude, and on his social interactions with his school colleagues and others around him. As the school superintendent expressed in the letter quoted in the Introduction, before entering the project Mike was "the quiet kid in the electric wheelchair" that "was there," and had demonstrated no leadership qualities. Mike's circle of friends was not very large, consisting mainly of his relatives and a few students at Cotting School. This, as Mike mentioned in an essay he wrote, further reduced his communication capabilities because people would get used to his speech difficulties, and they would anticipate what he wanted to say or do. Eight months after Mike started in the computer research project, however, changes in his attitudes were noticeable. This was mentioned in his psychological evaluation, in which the evaluator observed that:

> Mike is a bright personable young man who in many ways has risen above his physical affliction by becoming absorbed in many interesting activities. The computer has become an integral part of his daily thoughts, giving him a mental challenge as well as an opportunity for leadership. The teaching experience in which he is involved seems to be playing a large part in improving his self-esteem.

During the time this evaluation took place Mike had become responsible for the computer at the school, and was in charge of helping school classmates learn Logo. He introduced Logo to five students and was working with them as I had worked with him, although in a more interesting manner because he was much more patient and very relaxed when working with his colleagues. He did not have any of the awkward difficulties typically experienced by people interacting with handicapped individuals for the first time. He knew the problems of being handicapped and he could communicate easily with his schoolmates.

Through his work Mike was exposed to a number of people from outside the school environment. Several visitors came to the school to learn about his computer activities. He gave dozens of

demonstrations of his work and attended several conferences to help us to illustrate, with his computer programs, some of the points that underlie the Logo project with physically handicapped children. This exposure had a great impact on Mike's work. It revealed some of his weaknesses; for example, his typing difficulties. Once in a while Mike would be disappointed because he could not show all his programs -- people did not have the time to wait for him to type, load his programs into the computer memory, and cope with some unpredictable computer problems. On the other hand he found interesting ways of using the computer to compensate for these difficulties. The development of the BIG.SHOW project was directly related to the fact that he needed a way of maintaining his audience's interest without wasting their time. This program was extensively used and up to the last day of Mike participation in the project he was still improving it and introducing more interesting features.

Mike has also met several handicapped individuals who became interested in his work, viewing computer activities as a way out of their passive and dependent life style. He has established helping handicapped people become familiar with computer as one of his life's goals, hoping that eventually they might make a living by becoming computer programmers. Mike is in the process of setting up a non-profit organization so he can, through this company, work as a consultant in projects for the handicapped that involve computers; he wants to function as a bridge between the world of the physically handicapped and those institutions that are interested in providing this population with computer facilities. His ultimate objective is to make available to other people, like himself, the same experiences that he had. He is also considering the possibility of writing a book to document his experiences with Logo. As he says in a proposal that he is writing to a foundation, "The computer is a way that a disabled person can contribute to society."

5.9 Comparative Study

5.9.1 Baseline Data

In the development of Mike's Logo activities there were several programming and problem-solving solutions that he adopted which made his work quite original. In this section I

want to explore the question of how Mike's Logo activities compare with the Logo activities of a nonhandicapped, normal child.

The Brookline LOGO project (Papert et al., 1979) provides the baseline data against which Mike's work can be compared. This project was conducted at the Lincoln School in Brookline and involved 16 nonhandicapped students in the sixth grade. These were "average" and "exceptional" students at both ends of the spectrum of academic achievement. They worked in groups of four, with one computer for each student. The classes met four times a week, for periods ranging from 40 minutes to 90 minutes, with each student averaging 32 hours of exposure to Logo.

There was one student in the Brookline study, Gary, whose Logo activities quite nicely correspond with Mike's work. They have similar problem-solving styles, undertook similar Logo projects, and adopted similar solutions for similar problems. Before I begin to compare their activities, however, I should mention the process of collecting and documenting the work with students at the Brookline School was conducted independently of my work with Mike at Cotting School. Specific comparisons between the respective Logo research activities were not undertaken at this stage. Therefore, I do not feel that the comparisons being made in this section are biased beyond the educational values and practices shared by members on the Logo Laboratory in general.

Gary was 12-years-old at the time he participated in the Brookline project, and was considered to be "extremely bright" by his teachers. His overall score on his sixth-grade school achievement tests placed him in 83rd percentile. He found Logo to be an exciting challenge and he was one of the best students in the Brookline project. He worked on four major projects: use of arcs and circles to draw a face; creating a simple math quiz; drawing and animating a starship; and defining a computer program capable of translating Morse code.

5.9.2 Comparison Between Mike's and Gary's Logo Activities

Gary's initial introduction to Logo was not as structured as Mike's; Gary was allowed to play with the computer and to try out a few ideas on his own. On their first projects, however, both explored the repetition of simple procedures to produce drawing effects. Mike's procedures to produce the "winter wonderland" picture are shown in Figure 5.10.

```
TO PEN
10 FORWARD 100
20 RIGHT 30
30 FORWARD 100
40 RIGHT 120
50 FORWARD 100
60 RIGHT 30
70 FORWARD 100
80 RIGHT 90
90 FORWARD 100
100 HIDETURTLE
END

TO SQUARE
10 FORWARD 100
20 RIGHT 90
30 FORWARD 100
40 RIGHT 90
50 FORWARD 100
60 RIGHT 90
70 FORWARD 100
80 HIDETURTLE
END

TO S.P.S
10 SPIN 50
20 PEN
30 SQUARE
40 PEN
50 SQUARE
END

TO S.P.S4
10 REPEAT [S.P.S] 4
END

TO M.S.P.S4
10 MOVETURTLE 100
20 REPEAT [S.P.S] 4
END

TO 2M.S.P.S4
10 M.S.P.S4
20 M.S.P.S4
END

TO 2M.SPS4.6
10 REPEAT [2M.S.P.S4] 6
END
```

Figure 5.10

These procedures are similar in form to Gary's procedure FOO and then FOO2, which repeats the procedure FOO 10 times. In order to get a smaller figure Gary defined the procedure FOO3, repeated it 24 times in FOO4, and then played with FOO4, repeating it several times until he got a number of repetitions which would close the figure. Gary's procedures are shown in Figure 5.11.

```
TO  FOO
10  BK  50
20  RT  30
40  FD  20
END
```

```
TO  FOO2
10  REPEAT  10  [FOO]
END
```

```
TO  FOO3
10  BK  30
20  RT  10
30  FD  5
END
```

```
TO  FOO4
10  FOO2
20  REPEAT  24  [FOO3]
END
```

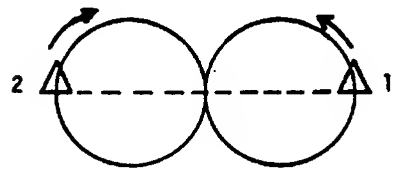
Figure 5.11

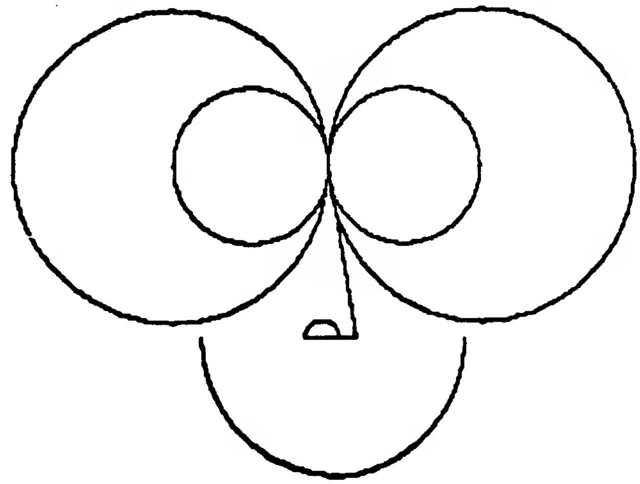
It is interesting that Mike, in his 2.MSPS4.6 procedure, while defining the number of repetitions for 2M.S.P.S4, adopted the same trial and error approach. He started with three repetitions and increased them until he arrived at six, the largest number of repetitions which would produce an aesthetically rich pattern on the screen that would not be so dense as to cause the computer to print an error message.

The picture that Gary produced by repeating FOO4, moved him to become interested in drawings using arcs and circles. He defined two procedures, FOO5 and FOO6 using the procedures LCIRCLE and RCIRCLE which draw left and right circle respectively. When he used these procedures with the same input for the diameter of the circle, the product resembled two eyes touching each other. Gary then became interested in drawing a face. The structure of his program, the procedures he defined, and the pictures they produced are shown in Figure 5.12.

This is quite similar to Mike's "Background of Copley Square" project, whose procedure TGDS is shown in Figure 5.2. Both started with simple ideas which then became major, complex projects. Both used hierarchical structures which involved very fine adjustments of the turtle to

draw each component of the picture in the right position on the screen.





```
TO FACE
10 ENM
END

TO ENM
10 EN
20 M
END

TO EN
1 EYES
2 NOSE
END

TO M
1 MOUTH
END

TO NOSE
1 FOO7
END
END

TO EYES
1 FOO6
END

TO MOUTH
10 FOO8
END

TO FOO6
1 FOO5
2 PENUP
3 LEFT 90
4 FORWARD 80
5 PENDOWN
6 RIGHT 90
7 RCIRCLE 45
8 PENUP
9 RIGHT 90
10 FORWARD 160
11 LEFT 90
12 PENDOWN
13 LCIRCLE 45
14 HIDETURTLE
END
```

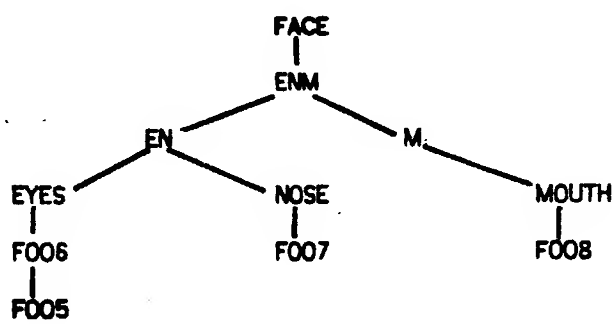


Figure 5.12

After these exploratory projects Gary was exposed to the idea of solving problems by dividing them into subproblems and then defining a superprocedure made of subprocedures. However, when he became involved in the STARSHIP project, he did not use this powerful problem-solving strategy. Both Mike, in the CAR project, and Gary, in the STARSHIP, repeated the same mistake of not dividing the problem into subproblems; both developed a long,

inefficient procedure, difficult to debug. Figure 5.13 shows both procedures.

Old Starship Procedure

```
TO STARSHIP
10 RIGHT 90
20 FORWARD 100
30 LEFT 90
40 FORWARD 50
50 RIGHT 180
60 FORWARD 100
70 PENUP
71 LEFT 180
72 FORWARD 50
73 LEFT 90
74 FORWARD 100
75 RIGHT 90
90 LEFT 90
95 PENDOWN
100 FORWARD 100
105 RIGHT 90
110 FORWARD 50
120 LEFT 180
130 FORWARD 100
140 PENUP
141 RIGHT 180
142 FORWARD 50
143 RIGHT 90
144 FORWARD 100
145 LEFT 90
155 PENDOWN
160 RIGHT 90
170 FORWARD 30
180 LEFT 90
190 FORWARD 30
200 LEFT 90
210 FORWARD 60
220 LEFT 90
230 FORWARD 60
240 LEFT 90
250 FORWARD 60
260 LEFT 90
270 FORWARD 30
280 PENUP
290 LEFT 90
291 FORWARD 30
292 RIGHT 90
300 HIDETURTLE
310 PENDOWN
320 RCIRCLE 10
330 LCIRCLE 10
340 PENUP FORWARD 30
345 PENDOWN
350 RARC 10
360 RARC 10
370 PENUP RARC 10
380 RARC 10
390 LARC 10
400 LARC 10
410 HIDETURTLE
END
```

New Starship Procedures

```
TO STARSHIP
10 STA
20 WINGR
30 WINGL
END

TO WINGL
10 MOV
20 LEFT 90
30 LI 50
35 RIGHT 90
40 HIDETURTLE
END

TO C
10 SQ.1
20 PENDOWN RCIRCLE 10
30 LCIRCLE 10
40 PENUP FORWARD 30
45 PENDOWN
50 REPEAT [RARC 10] 2
60 PENUP REPEAT [RARC 10] 2
70 PENDOWN REPEAT [LARC 10] 2
80 PENUP REPEAT [LARC 10] 2
90 BACK 30
END

TO STA
5 WRAP
10 C
20 LI 100
END

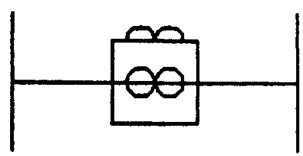
TO MO
10 RIGHT 90
20 FORWARD 100
30 LEFT 90
END

TO WINGR
10 MO
20 RIGHT 90
30 LI 50
40 MOVE
END

TO MOV
10 LEFT 90
20 FORWARD 100
30 RIGHT 90
END

TO LI :LE
5 PENDOWN
10 RIGHT 90
20 FORWARD :LE
30 LEFT 180
40 FORWARD 2 * :LE
50 RIGHT 180
60 FORWARD :LE
70 LEFT 90
END

TO SQ.1
5 PENUP
10 RIGHT 90
20 FORWARD 30
30 RIGHT 90
35 PENDOWN
40 FORWARD 30
50 RIGHT 90
60 FORWARD 60
70 RIGHT 90
80 FORWARD 60
90 RIGHT 90
100 FORWARD 60
110 RIGHT 90
120 FORWARD 30
130 RIGHT 90
135 PENUP
140 FORWARD 30
150 FORWARD 30
END
```



STARSHIP

Figure 5.13

Another interesting aspect about these projects is that both were developed with the idea of animating a drawing. Both Mike and Gary, however, again had the same bug -- using the HOME command which made animating the pictures impossible.[1]

The last project that Gary developed was a Morse code translator, an idea taken from a computer hobbyist magazine. This project consisted of identifying input letters from the alphabet and producing the corresponding Morse code. The idea is very similar to Mike's project to draw words on the computer display. In fact, both students adopted the same solution to identify the input letters. Gary's CODE procedure outputs a correct sequence of dots and dashes for any letter. Mike's LGR procedure draws the corresponding letter on the computer display. Figure 5.14a and figure 5.14b show both procedures.

```
TO LGR :M :X :Y :L
10 IF :M = "A A :X :Y :L
20 IF :M = "B B :X :Y :L
30 IF :M = "C C :X :Y :L
40 IF :M = "D D :X :Y :L
        .
        .
        .
        .
250 IF :M = "Y Y :X :Y :L
260 IF :M = "Z Z :X :Y :L
270 IF :M = "↑[ ↑[ :X :Y :L
280 IF :M = ". . :X :Y :L
END
```

Figure 5.14b

```
TO CODE :LET
10 IF :LET = "A OUTPUT [ . - ]
20 IF :LET = "B OUTPUT [ - . . . ]
30 IF :LET = "C OUTPUT [ - . - . ]
40 IF :LET = "D OUTPUT [ - . ]
        .
        .
        .
        .
390 IF :LET = "; OUTPUT [ . - . - . - ]
400 IF :LET = ": OUTPUT [ - - - . . . ]
410 IF :LET = "? OUTPUT [ . . - - . . ]
420 IF :LET = "" OUTPUT [ . . - . . - . ]
END
```

Figure 5.14a

Another interesting similarity between Gary and Mike, beside their projects, was their problem-solving styles. Both students tended to approach problems with very little advance planning, and then had to spend a long time debugging their original ideas and reprogramming their procedures. A closer look at their work shows that they did not have any difficulty with

1. The HOME command places the Turtle at its home position -- center of the screen -- and "freezes" it. After commanding the Turtle to go HOME, the Turtle will have no speed.

LOGO commands or with the definition of procedures; they did not have problems understanding reverse commands, i.e., that BACK produces the opposite effect of FORWARD; they did not have problems combining commands; they developed new projects using previously defined procedures; they were very meticulous about their final products; and they both had quite original ideas for their projects drawn from a variety of sources.

The basic difference between Gary and Mike was their rate of progress. Gary, for example, managed to learn to apply recursion much faster than Mike. Gary developed his projects in approximately 32 hours while Mike, who had the computer exclusively available to him, took approximately 150 hours to develop the work just discussed. However, I would argue that it is misleading to contrast "the amount of work done" between between these youngsters since there were many prerequisite skills for success with computers which Mike had to achieve from scratch. Gary began with a facility for debugging his programs more efficiently. He could play computer, write down the results of his programs, and plan in his notebook before starting new projects.

Gary's project ended before he had a chance to explore the sophisticated programming ideas which Mike eventually learned. This prohibits a more thorough comparison between Mike's and Gary's performance. The main point here is that Mike's programming demonstrates that his handicap has caused a delay in developing learning skills, rather than a deviation from the development of a normal child.

5.10 Conclusion

We have seen that Mike's LOGO activities required him to learn new academic subjects and new skills. This is an indication that his brain lesions were not impeding learning from taking place. Since the onset of the computer project, his writing and programming activities, as well as his social interaction skills and his motor coordination, have shown significant improvement. Again, this indicates that his deficiencies may not be attributed to brain lesions but to a general lack of experience; it is, of course, impossible to know how much the brain lesions will prevent him from

reaching higher levels of intellectual development. Thus, we may conclude that delays in Mike's development are at least partially and, perhaps substantially, a result of lack of experience.

Another important conclusion we can draw from Mike's computer activities is that the Logo environment provided him with an excellent opportunity for revealing his incredible creative capacity, and for overcoming some of his weaknesses. This was not done by setting up remedial perceptual programs, as proposed in the cerebral palsied literature, or by designing a contrived learning environment. Quite the contrary, I tried to deal directly with Mike's deficiencies. I made available to him the necessary information he needed in order to solve his problems, and I tried to provide remedial programs that would directly address the weaknesses he had shown in his activities. The side product of this educational approach was that in problem solving we also create the conditions for Mike to develop those academic skills that helped him to reach higher levels of education. The Logo environment provided Mike with the opportunity to carry out activities he could not have done otherwise, while simultaneously providing him with the means for acquiring a potential career.

Mike is a creative person who, as he parents say, has always liked to develop original ideas. Prior to his experience with Logo, however, Mike could not carry out the majority of his ideas; he had to depend upon others to implement them. The computer provided him with the means to untrap his mind and so demonstrate his true potential. It showed that he is capable of acquiring new knowledge and that he can be independent from others. As he has said many times, "The computer has opened many doors for me." And I would like to be able to provide the same experience to other cerebral palsied children. The question, then, becomes "Is it possible to find another "Mike" who could experience the same development." In another words, how much of Mike's success depended upon his personality. It is conceivable the experience with Mike can be repeated with another handicapped person. However, it is quite clear that the pathways are going to be completely different. Considering that each cerebral palsied person has different experiences, and that brain lesions can vary enormously, it is more realistic to assume that each

individual constitutes a unique case, and needs to be treated accordingly. Thus, the solution to the education of cerebral palsied children is to provide them with a rich learning environment, flexible enough so each individual can follow his own interest, and, by doing so, evolve according to a developmental pattern that is unique. The crucial point is that each one of these individuals has a chance to reach the goal he has set up for himself. How he gets there may vary, and this may not be important. One can argue that this makes generalization of education techniques impossible. However, this may not be the case. We may not be able to generalize particular solutions, although the fact that I adopted a working methodology which facilitates Mike's skills development should be an experience that can be transferred to other cerebral palsied individuals.

What is described here does not do justice to the development of this human being. All I can try to do is give a sketch of the kinds of development that took place and to give some insight into key themes that emerged from Mike's computer work -- in particular the role of a sense of control, the degree of willingness to improve, and the desire for elegance in a person with little opportunity for aesthetic expression. The aim is to provide a model of how physically handicapped children can acquire academic skills in a environment that is rich of ideas and opportunities for the development of the whole person.

Chapter 6

James' Case Study : Understanding Idiosyncrasies

In this chapter I describe James' Logo computer activities. James was 13-years-old when he began working on the Logo project in April, 1979, and continued his participation until the end of the 1982 school year. when the project ended. He is a spastic quadriplegic cerebral palsied, and has limited use of his limbs. Although James' psychological and educational progress have been constantly evaluated due to his neurological disability (hydrocephalus), these evaluations have failed to present a complete picture of his cognitive development. James' capability to manipulate objects and his writing skills have never been evaluated because of his motor impairment, and the evaluations have not identified the compensatory mechanisms that James has developed to cope with his disabilities. As a result recommendations suggested by the evaluators have not helped James to meet his practical needs -- they do not propose specific remedial programs to help James overcome his deficiencies.

The objectives of this chapter are to demonstrate: (a) how the Logo computer-based learning environment helped to pinpoint areas of strength and weakness in James' cognitive abilities; (b) how remedial programs were developed to overcome deficiencies observed in James' activities; and (c) how James could benefit from the computer technology in terms of developing a vocational career and becoming more independent.

6.1 James' Background

In April, 1979 when James started to work with Logo he was 13 years and 3 months old, enrolled as a 4th grade student in the Cotting School for Handicapped Children in Boston. He is a severe

quadriplegic spastic cerebral palsied, due to hydrocephalus.[1] A shunt was placed on the right side of his brain after which James exhibited a greater motor impairment in his lower limbs and in his left arm. He has good functional use of his right arm for most daily tasks. He is able to feed himself and propel his wheelchair. He can handle small objects, provided he is supported in his wheelchair and the objects are placed within his reach. However, his fine motor control is inaccurate and slow. His written work is barely legible, as indicated by the sample in figure 6.1. His speech is mildly unintelligible -- he is able to monitor his speech and improve intelligibility by pacing himself.

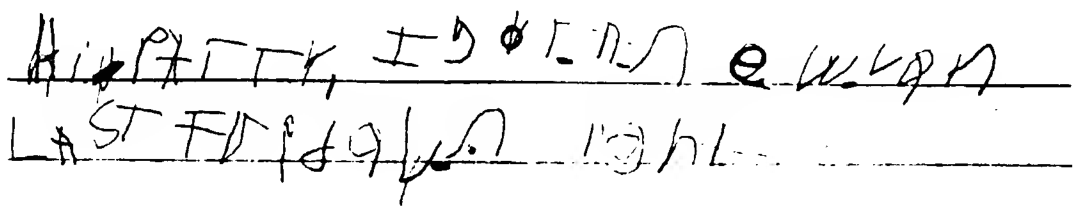


Figure 6.1

The placement of the shunt in the right hemisphere of his brain may have caused severe lesions in this region. These lesions may have implications for the development of cognitive functions supported by the right hemisphere, such as spatial related functions (Hecaen and Albert, 1978; Luria, 1980). James' mild motor impairment in the right side of his body, however, indicates that the left hemisphere may also be damaged, although not as much as the right hemisphere. The difference in degree of hemisphere lesion may have caused a imbalance between the activities supported by the two hemispheres; that is, language skills, known to be supported by the left hemisphere (Hecaen and Albert, 1978), may be superior to spatial-related skills, known to be

1. Hydrocephalus is caused by an excessive accumulation of cerebrospinal fluid within the ventricles. Progressive hydrocephalus requires a shunt procedure to reduce the pressure within the brain. The placement of the shunt may also cause brain lesions, and if motor areas are affected the child acquires the symptons of cerebral palsy.

supported by the right hemisphere (Hecaen and Albert, 1978). Thus, it would be interesting to investigate whether there is a imbalance between James' language skills and his spatial-related skills.

Due to James' neurological condition his intellectual capabilities have been under constant evaluation. These evaluations are prime examples of the issues that I discussed in Chapters 1 and 2. They concentrate on intellectual deficiencies in terms of visual-perceptual disabilities, and they neither evaluate James' capacity to learn and think, nor do they identify James' strengths (such as his writing skills), or the compensatory mechanisms that James had developed. This ability to develop compensatory machanisms is an important aspect of James' cognitive capability because it points to a solution to the problem of how James might overcome his disabilities and develop a vocational career.

At the Cotting School, James' fourth-grade teacher observed that his performance in science, social studies, arithmetic, handwriting, and phonics, was at grade level, while his language and spelling grades were at a third-grade level, and oral reading and reading comprehension grades were below third-grade level. The teacher reported that James' strength was his auditory skills, such as listening, becoming involved in conversations, and discussions. The goals the teacher set up for James were "to learn to work independently, and to develop written communication."

James was also being seen in the Resource Room for mathematics and reading comprehension. In October, 1977 the Resource Room teacher's report indicated that:

> James' major areas of concern are motor deficits and visual perceptual problems. He also has a general attentional problem. James poor abilities could stem from his poor motor control, poor visual perceptual abilities, and possible visual acuity problems. His main areas of weakness are discrimination and directionality problems. Most of the time reversals are made in letters and numbers when reading or writing. Directions have to be stated slowly, clearly, and repeatedly. James has a very short attention span and is easily drawn away from his task at any auditory distraction in the room....James has average expressive language and is adequate in general information. He looks for approval, adult reinforcement, and praise in performing any given task. Because of his needed attention, James has difficulty in working independently.... James should be placed in as quiet a setting

> as possible to decrease auditory distraction. He should also have a very structured program to increase ability to work independently. The program should be explained explicitly in order that James knows what is required of him. The teaching materials should be large, bright, and concrete. If worksheets are used again they should have large print.

These findings were confirmed by evaluations conducted by the Cotting School using psychological and educational tests. Due to James' limb impairment he has been evaluated only with tasks that do not require manipulation of objects. In November, 1979 the verbal tasks of the WISC were administered, and James was given a verbal IQ of 91, placing him at the normal or average range. The evaluator observed that "Elevated subscores suggest strength concentration in vocabulary development and in finding general information. Lowered subscores indicate weaknesses in dealing with numerical symbols as well as in mental shift," and concluded, "This profile evidences a child who is involved with the world around him and is alert to events and happenings in society....The issue of mental shift would probably be related to brain insult and would therefore be limited to the extent of recovery. It would be helpful to do some limited exercises in this area to establish optual level."

Another evaluation done by a clinic in Boston in September, 1980, while James was beginning the fifth-grade, found the same deficiencies mentioned above and indicated other problems: visual perceptual difficulties on picture memory tasks; delays in the development of his vocabulary, in his ability to think abstractly, and to form social judgment; limited ability to scan pictures and derive their meaning (performing at second grade level); and difficulty in applying mathematics concepts (performing at second grade level) although numerical reasoning was at an early fifth-grade level. The clinicians also found that although James was still denying the full impact of his handicap, as expressed in his nonrealistic plans for almost total independence, he had very high vocational aspirations, and was concerned with issues of mastery, plans for the future, and social adjustment. No recommendation was made about which vocational career James should pursue.

There are four points to be made about these psychological and educational evaluations. First, the teacher's recommendation that James should work with greater independence suggests that James, not the activity, is deficient. When James worked on the computer, however, I found him to be able to spend as much time on task as normal children. During James' computer sessions, he would often work on a problem for two or three hours without any interruption. He was aware that he was working hard and that he had stayed longer than he should --- he would say that he had stayed longer because he enjoyed the work he was doing. Thus, James knew how to be independent, and how to work hard. What prevented him from doing so was the interest he had in the activity he was engaged in. If the activity -- be it a game or an exercise in mathematics -- has no interest for James, he will behave as if he needs constant attention. The solution, then, is to find interesting and challenging things for him to develop.

Second, the evaluations indicate that he has visual-perceptual difficulties and a low attention span, and that he should be placed in learning environments with low background activity. This recommendation is consistent with Cruickshank's reduced-stimuli theory (Cruickshank, 1976b). However, this recommendation does not seem to be the most appropriate solution to James' problem. As noticed by the evaluators, James is a boy who has a great desire for interacting with people, who is concerned with his social adjustment, and his "strengths lie in his personality, sociability, orientation to achievement, and determination." He needs to be in an environment rich with opportunities and to be able to produce things so he can demonstrate to himself and to the people around him that he is capable. This was what he did in the Logo environment. He used the computer text-editor to produce a weekly newspaper, which he delivered to his teachers and friends. Because this was an important activity James took great pride in functioning as the newspaper writer and the "newspaper boy." He listened to the radio to get interesting news, stories, talked to people to find out what was happening, and kept up with the school events and even current jokes to use in his paper. The "low background activity" defended by Cruickshank's theory misses the point: only meaningless "stimulation" needed to be reduced. James, indeed, could not get enough meaningful "stimulation."

Third, these evaluations did not help James develop a vocational plan. They indicated that he was concerned with his future, but said nothing about which careers James should pursue. The evaluator's difficulties are quite understandable. They were faced with a patient who has limited use of his hands and who cannot fully interact with the physical world, while knowing that most jobs require such abilities. These evaluators ignore, however, the current status of computer technology -- they are not aware of the potential of the "information industry," which does not require people to be able to manipulate objects, but only to be able to push buttons. The computer is the tool that James needs when he considers a vocation. While developing his newspaper, James mentioned that he would like to be a writer. This possibility should not be discarded without thought. Communication is his strength. James was doing what he is best at, and was learning a great deal about writing, spelling, and the organization of ideas -- a good example of strengths supporting weaknesses.

Finally, the evaluations do not point to James' specific difficulties in order to provide remediation. If he cannot apply his mathematics skills to practical problems, as the evaluators found, the question becomes, "What activities should he develop to help him acquire this knowledge?" It is obvious that this is not the kind of knowledge that he can learn using a blackboard. James should be involved in activities that allow *him* to access his knowledge and put it to work. Normal children probably become engaged in these activities by being active in their environment -- by going to the grocery or by exchanging marbles. The physically handicapped, who is excluded from these natural experiences, needs equivalent opportunities to apply his knowledge.

James' computer work showed that he has a very limited assortment of problem-solving techniques. For example, he did not have the notion of correcting a mistake, "debugging" in computer terminology. In fact, as a way of avoiding the problem, for a long period of time he never admitted he had made a mistake. He would say that everything he produced was perfect and was exactly what he wanted. I was not surprised to find that the evaluator had reported that

James had never admitted his handicap. It became clear that James would benefit from computer activities.

We wanted to demonstrate the function of the computer as a tool to diagnose and remediate weaknesses, and James fit perfectly into the objectives of our research. As the evaluations indicated, James had never performed any task that required him to manipulate objects. His writing skills had never been evaluated. Thus, if we provided him with the means to perform these tasks we would be in a position to identify James' cognitive skills in a more complete and meaningful way than had the evaluator. We would be able to study whether James' right and left brain lesions caused a dissociation between his abilities to perform language-related tasks and spatial-related tasks. This is what we set out to do.

6.2 Summary of James' Computer Activities

During James' participation on the research he had the opportunity to use the computer to perform linguistic and spatial-related types of tasks.

James' computer activities were not developed over a continuous period of time, as were Mike's. Unfortunately, James' activities were interrupted by periods of hospitalization or illnesses which required him to stay out of school. James used the computer differently in each of these periods. Figure 6.2 depicts these different periods, the activities James developed within each period,[1] and his incidence of medical treatment.

1. The DRAWING program is a rudimentary version of a Button-Box, described in the Introduction. Seven keys on the computer keyboard, chosen to be well separated, are labeled according to the function they perform. For example, a label "forward" can be placed on the P key. When this key is hit, the Turtle moves forward 10 steps. In addition, the DRAWING program keeps track of all the Turtle's moves and converts them into a procedure that can be used to reproduce the same drawing later. The seven labels attached to the keyboard were: forward, back, right turn, left turn, penup, pendown, and clear screen.

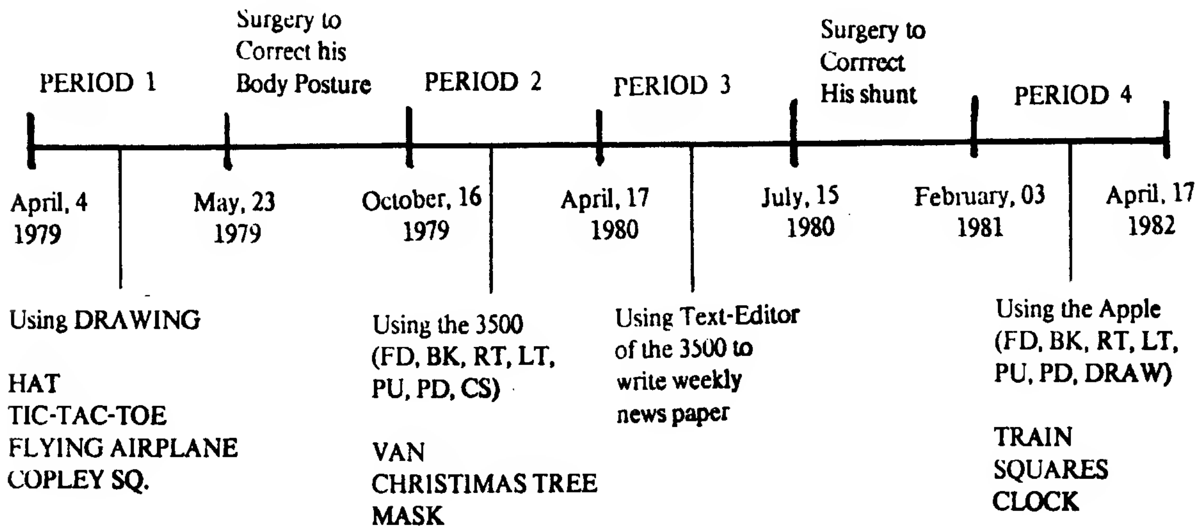


Figure 6.2

James had two sessions of approximately 40 minutes, twice a week. A typical session would start with James coming to the Cotting School computer center by himself. I would set him up at the computer, and he would start his work. Initially he would review the activities he had done so far, and, then, he would continue the activity he was working on. This working style was used either while he was doing drawings or writing. I would work with him individually to observe and take note of his behavior, his difficulties, how he solved them, and how I needed to intervene to help him. As much as I could I would encourage James to work independently, and to solve his difficulties by himself before he asked for help.

Instead of giving a detailed description of James' computer activities, following a chronological order in which they happened, I want to use James' activities to illustrate how the computer can be used to diagnose cognitive strengths and weaknesses. James' computer work will show a imbalance between his writing and drawing skills; and it will show two compensatory mechanisms he developed to cope with his weaknesses. I will also illustrate how James' weaknesses can be overcome through the use of Logo activities and remedial programs.

6.3 Imbalance Between James' Writing and Drawing Skills

A comparison between James' writing and drawing skills indicates that the former are superior to the latter. In terms of mastering the Logo language to produce drawing, James did not accomplish in two years what Mike, for example, accomplished in his two first Logo sessions. James was not able to progress beyond the use of Logo commands to drive the Turtle, and he never reached a level of being able to define a procedure. In order for James to develop his projects I had to provide him with procedures to draw parts of his drawing. On the other hand, James' writing skills were far superior to Mike's.

The results of evaluation tests, and observations made by James' teachers, indicated that James' verbal skills were at grade level. However, his writing skills had never been evaluated -- James' motor impairment had prevented him from producing written material. Through the use of the computer text-editor James was able to engage in writing activities, producing several weekly newspapers and letters to his friends. Writing on the computer became one of his favorite activities. His computer writing showed that he had no problem planning his activities and organizing his ideas. For example, in the production of newspapers, he would start with the section headings and then would go back to fill in details in each section. He would start with the section that was the easiest and then proceed to the other sections. If at the end of the week some of the sections were not filled he would erase them. This type of structure indicates a top-down problem-solving approach, a similar method to that used by expert computer programmers. Figure 6.3 shows a stepwise development of one of James' newspapers. [1] This example indicates that the structure of the sentences James used is grammatically correct, does not have missing words, and that he uses phonetic spelling.

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1. In this example I omit intermediate steps. NEWS3#1 refers to the first step of the third newspaper he produced. NEWS3#7 refers to the seventh step, and NEWS3#11 is the newspaper version that James considered to be the finished version. This version was, then, corrected by him after I pointed out spelling errors which he corrected in the final version (NEWS3#13).

```
                NEWS3#1        1 Block         Printed 9/26/80
COMICS

SPORTS

SHOWSHAL

HARSCOSP

INVEARTEING REPORTS
SCHOOLS REPORTS
HIY
```

```
NEWS3#7        1 Block         Printed 9/26/80

COMICS
A MAN NOWS GREW AND GREW AND GREW WHIN HE TELLED A LIY

SPORTS
LAST NIGHT THE BOSTON RED SOX BEET THE NEW YORK YANKES 7-2

SHOWSHAL

HARSCOSP

INVEARTEING REPORTS
SCHOOLS REPORTS
HIY SCHOOL SPORTS

  CALL SCHOOL SPORTS
@@@@
```

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NEWS3#11        1 Block         Printed 9/26/80
JOHNNY'S NEWS PAPER

COMICS
A MAN NOWS GREW AND GREW AND GREW WHIN HE TELLED A LIY

NEWS
THERE WAS 4 BOYS HOOW WHAT OUT IN THE BOAT FOR A BOAT AND THE BOAT
TRARND OVEN AND ONE BOY WAS DEAD ON A RIE FJL

SPORTS
LAST NIGHT THE BOSTON RED SOX BEET THE NEW YORK YANKES 7-2
LAST NIGHT THE BOSTON RED SOX BEET THE NEW YORK YANEEKES IN 10  IN
ING 4-3

MY TWIN SISTER CALLEM
MY SISTER GRAJUWHATDID FROM JOON U HIEY SCHOOL AND NIXT YEAR SHE IS
GOING BE GOING TO POKE JOHN

HARSCOSP

INVEARTEING REPORTS
SCHOOLS REPORTS
HIY SCHOOL SPORTS
```

Figure 6.3

Although James' newspaper revealed several aspects of his writing skills, they do not give a clear picture of his abilities to convey a thought or how to carry a discourse in writing. These capabilities are illustrated by a letter that James wrote to one of his friends, shown below.

> Dear Winde
>
> How are you doing
> Iam fine Iam warking at MIT dooring the sunmmer
> Working on the canptrse for the sunmmer and thin I will go back to
> school in the fall and I will whork hard
> triying to get a prmoshin
> To doing work on the canptrse so I can arned a living.
> Iam doing droing news papers
>
> My a dress at MIT
> 545 Tech Square room 339
> Cambridge Mass 02139
>
> Love James

According to James' teacher the quality of this writing is at his grade level. Compared to Mike's first writings, James' writing skill is much superior -- it does not have the disorganization found in Mike's writing, as I discussed in section 5.6. James' biggest problems are spelling and punctuation. In contrast to his abilities to solve problems involving spatial reasoning, James' writing shows great potential. In view of this imbalance between writing and drawing skills, the questions of interest are: (a) "Is it possible to identify weaknesses in his drawing skills which contribute to the underdevelopment of his drawing capabilities?"; (b) "If weaknesses are identified, is it possible to overcome them through the use of remedial programs?"

6.4 Turtle Drawing Activities: Diagnosing and Remediating Weaknesses

The objective of this section is to show how Logo can be used to diagnose and remediate weaknesses in James' abilities to use Logo to produce drawings. The analysis of James' drawing activities indicates that (a) James had great difficulty estimating distance. This was revealed by numbers he chose as inputs to Logo commands. What could have been done with one or two commands would take him five or more. This weakness was overcome through the use of a remedial program for estimating distances; (b) James had difficulty admitting he had made a

mistake, which prevented him from learning from his mistakes. This deficiency was overcome through his Logo activities, rather than through the use of a specific remedial program; and (c) James developed several compensatory mechanisms to cope with these two deficiencies. Although these mechanisms were not entirely appropriate to the specific problem in consideration, it indicated that James could develop better mechanisms for overcoming his disabilities.

6.4.1 Estimation of Distance and Use of Number Inputs

When I introduced James to Logo commands, I suggested he draw a square. In his first attempt he got an irregular triangle. In his second attempt he got an irregular hexagon because the number inputs he used for the commands were in sequential order -- FD 100, RT 101, FD 102, and so on -- rather than being based on the geometric significance these numbers could have. The irregularity of the picture, and the fact that it was not a square did not bother him.

It is important to mention that it is not unusual for beginner Logo users to select numbers in sequence. One often sees idiosyncratic number selection, such as numbers whose digits are next to each other in the computer keyboard, -- e.g. 34, 67, -- or favorite numbers. However, as users progress in their interaction with the Turtle they spontaneously try to use numbers in a more contextually. James differed from other users by not exhibiting the same development in the selection of numbers. Thus, while I was working with him I would encourage James to use decadal numbers, or multiples of 5, and to try to choose numbers based upon previous commands. In general he would take my suggestions. Every time I left him on his own, however, his number selection would follow a sequential pattern.

This was clear when he developed the Christmas tree project, which he worked on mostly on his own. The Christmas tree project started right before Christmas. To help James finish it before the holidays, I provided him with the procedures to draw the parts of the Christmas tree. These parts and the name of the respective procedures are shown in figure 6.4. James' task was to assemble these parts, and decorate the tree.

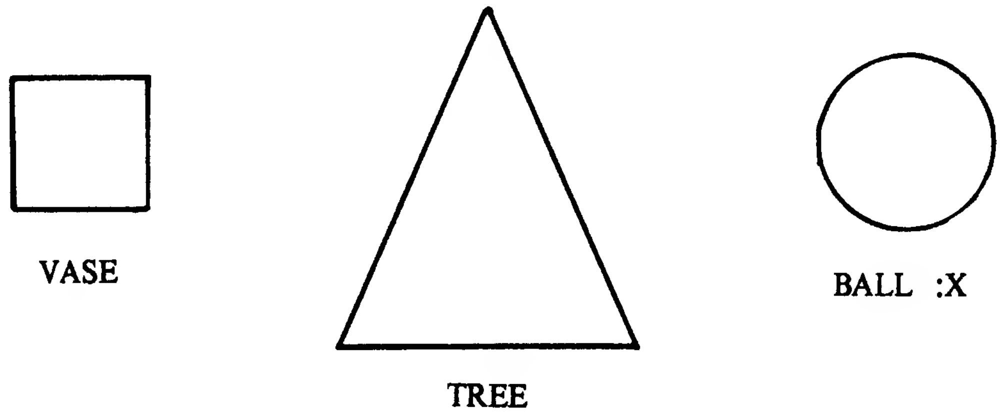

Figure 6.4

To move the Turtle to the top of the tree so he could place a star there, he used a series of eight forward commands, starting with FORWARD 14, since 14 was his age at that time, up to FORWARD 21. The sequential selection pattern would be used regardless of the command in consideration. For example, when James was placing the balls around the tree, he used the following commands, which produced the drawing shown in figure 6.5.

```
BALL 9
FD 10
BALL 11
HT
ST
FD 12
BALL 13
FD 14
```

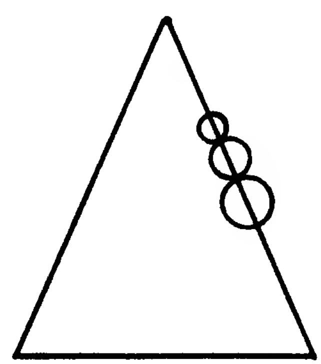

Figure 6.5

These commands indicate that James invoked the successor function rather than estimate the distance on the basis of which he would select the number for the input of the command. It is important to notice that 5- to 6-year-old normal children can use previous experience to guide

their selection of numbers. These children estimate the number for the next command based upon numbers they used in previous commands and how far the Turtle moved or turned. Instead, James would invoke a piece of knowledge that was not appropriate for the situation. However, he was confident in his strategy. In order to accelerate his progress I decided to help him to focus on the problem of estimating distances. I developed a remedial activity which functioned to provide James with situations in which he would need to select an appropriate number to move the Turtle a given distance. This was done through a game that I called the "target game."

The target game consists of displaying a target (a square) on the computer screen, while the Turtle, called the missile, is displayed resting on a line drawn at the bottom of the screen, as shown in figure 6.6a. The goal of the game is to give a command to the missile (FORWARD or BACK), so the missile can hit the target. A hit is rewarded with an "explosion" of the target that is proportional to the number of commands that are used to move the missile. Thus, if the target is hit by using one command the explosion is the largest, as shown in figure 6.6b; if it takes four moves the explosion is small, as shown in figure 6.6c. As the missile moves it leaves a trace. The distance between the base line and the target is marked on the screen. As the game progresses, a series of targets appear on the screen, each at different heights.

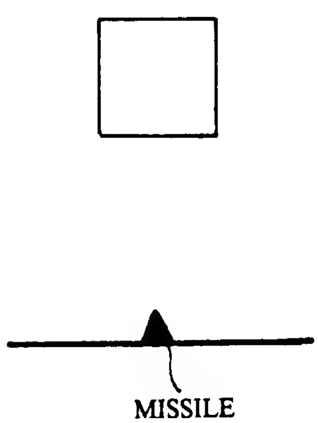

Figure 6.6a

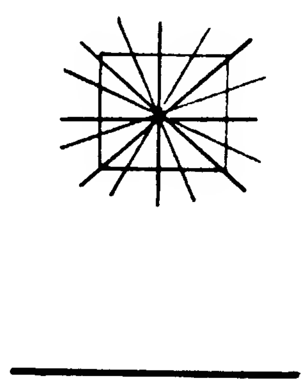

Figure 6.6b

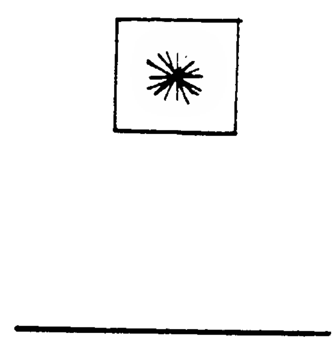

Figure 6.6c

The game encourages the user to try to hit the target in one estimate; to use numbers in sequence requires a large number of commands and the explosion will be minimal.

The first time James played the target game he used the sequential strategy to select number inputs and was disappointed with his performance. Gradually he understood the objective of the game. He played the game for five sessions and by the fifth session he was hitting the target in one shot. This improvement in his abilities to estimate distance was transferred from the target game to his drawing activities. He stopped using numbers in sequence, and instead selected numbers appropriate to the distance. He began to use decadal numbers as standard. For long distances he would use a 3-digit numbers, such as 100 or 120; and for short distances he would use small numbers such as 10 or 20. This strategy was used throughout the TRAIN and the CLOCK projects. It was used either for selecting numbers or to move and to turn the Turtle.

Thus, by providing James with a remedial program that allowed him to exercise his abilities to estimate distances and to select numbers for the Logo commands, it was possible to observe a remarkable improvement. This improvement indicates that: (a) although estimation of distance is a spatial-related task, James' deficiency in this task was correctable. At least in this case, it seems that either the brain areas that support this activity were not significantly damaged, or he developed compensatory mechanisms to cope with the deficiency. In either case these findings lead us to derive three principles we should keep in mind while dealing with cerebral palsied children. First, not all the intellectual dysfunctions observed in cerebral palsied children are due to brain lesion. Second, before we conclude that cerebral palsied children's brain lesion impairs learning, we should provide these children with meaningful activities to investigate whether their disabilities can be improved. Third, the fact that some disabilities can be overcome through experience does not mean that this can happen with all disabilities. Some dysfunctions may be supported by brain areas that are in fact severely damaged. In this case the child has to find other ways of compensating.

6.4.2 Accepting Mistakes and Debugging Them

From the very beginning of his Logo drawing activities James seemed to have difficulty accepting his own mistakes. The first indication of this was his inability to stick to the original goals of his project.

James was introduced to Turtle drawing by using a DRAWING program, in which he could command the Turtle by hitting one of seven keys on the computer keyboard. This was a quicker way of having James use the computer to produce drawings than using Logo commands. With the DRAWING program he could command the Turtle by using only a few typing gestures, and he did not need to pay attention to details of command syntax, such as the "space" between the name of the command (FORWARD) or the input (number) to the command. Also, by using this program he could learn the concept that each action of hitting a key would correspond to a particular Turtle's response. This notion may not be obvious to a person who has had almost no direct impact on the physical world.

The drawing shown in figure 6.7, produced with the DRAWING program, illustrates how James would change his goals in midstream.

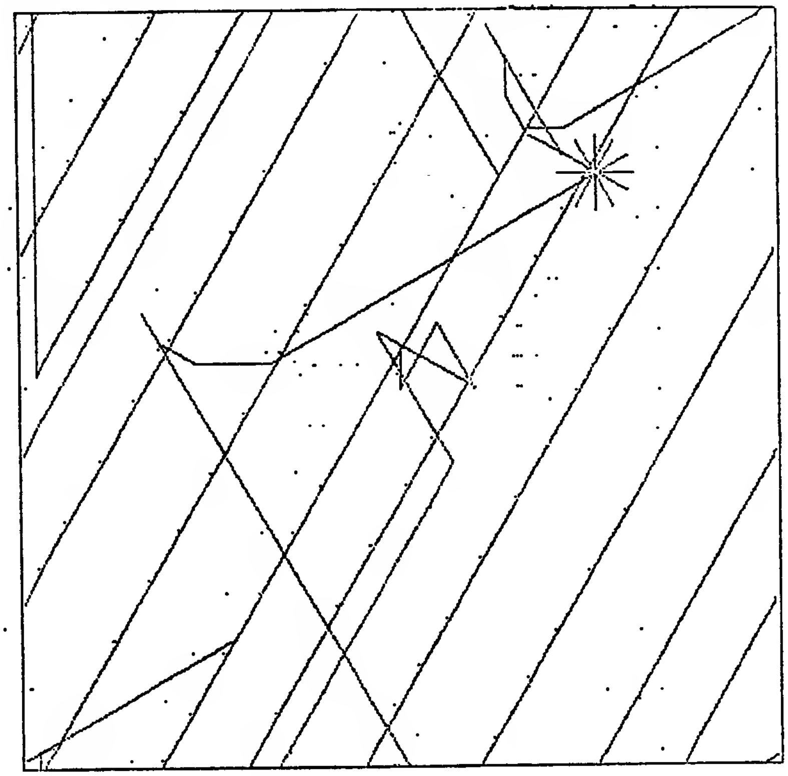

Figure 6.7

The project started because he wanted to draw a cross. He did the vertical line, but when he turned the Turtle to get the horizontal line he turned too much and got a line that was at 120 degrees from the vertical orientation. At this point he said he wanted to draw a star. Before he finished the star, the line at 240 degrees from the vertical orientation became too long. James said that that was correct because he wanted to draw another cross. He produced the horizontal line of the second cross, turned the Turtle 30 degrees and continued hitting the forward button. At this point he said he had another idea, although he did not express it. He kept hitting the forward and the turning buttons, and when he had several lines on the screen he said that he was drawing a "picture of an airplane that flies and then explodes."

At the first indication that something was going wrong James would change his project goal, and would incorporate this unanticipated result into a new project goal. His problem was that he never tried to figure out what was wrong. If he made a mistake he would never go back to correct it by, for example, erasing the screen and starting over. Instead, he would proceed with new goals.

The fact that James never kept with the same project, makes it difficult to understand what he knows about angle, distance, and the application of these concepts to a practical situation. By always claiming that his actions were intentional he made it difficult for us to evaluate his knowledge. Thus, the first step towards helping James to admit his mistakes was not to let him change the intention of the action which produced the mistake. But this was to ask for a profound emotional change in James' sense of himself and way of relating to the world. James' physical impairment deprives him from acting on the physical world and from confronting the result of that action. When James has people implementing his ideas they can obscure the omissions in his thinking -- he is never directly responsible for any failure that his ideas might cause. He always can blame the failure on the person who is implementing them, often someone who will help James to avoid his difficulties. The people around James, though well intentioned, may well have contributed to his misunderstanding of reality. The question, then, becomes, "What can we do to help James develop more constructive coping mechanisms?" This is a serious and delicate question because the changes needed to happen at a pace James can accept. This represented a difficult situation to remediate. On one hand, we could not keep James ignorant of the reality around him. On the other hand, we did not want to make him aware of mistakes he cannot confront.

Thus, instead of directly confronting James with his mistakes, I decided to introduce constraints in his activities by lengthening his projects. James was able to accept these new rules because other incidents in his life took place which led him to feel better about himself and feel ready to accept responsibility. James underwent a surgery to correct his body posture. After the operation he could sit straight on his wheelchair and was no longer in constant pain, which had certainly contributed to his impatience. In addition, he had become a fifth grader student. According to the school regulations James was supposed to be more responsible for his work -- he had to attend different classes, he had more than one teacher, and he was required to work independently.

This combination of factors caused James to show more interest in developing long and elaborate projects. He also wanted to use Logo commands to "program the computer" instead of using the DRAWING program. I introduced him the Logo commands FORWARD, BACK, RIGHT, LEFT (which he discovered on his own), PENUP, PENDOWN, and CLEARSCREEN. In addition, I provided procedures to draw geometrical shapes such as SQUARE, TRIANGLE, LCIRCLE (to draw a circle to the left), and RCIRCLE (to draw a circle to the right). As his first project James decided to draw a picture of his van.

The constraints that I had introduced did not completely stop him of making minor changes in his project. For example, at one point in the van project James had to use the LCIRCLE to draw the back wheel of his van. Before he did it he expressed his plans, and made sure he was going to draw the wheel. Instead of using LCIRCLE, he used RCIRCLE which drew a circle above the line representing the bottom part of the van -- that is the "wheel" was inside the body of the van. He immediately said that he intended to use the circle as the back seat of his van. Then he proceeded to use the LCIRCLE to draw the back wheel.

Even though James was still avoiding debugging, there was some improvement in his behavior. He kept the overall plan for his project. My hope was that eventually a situation would arise in which he would admit error. Indeed, that happened while he was working on the ornamentation of the Christmas tree -- to draw balls around the tree. He used the BALL procedure and imposed two constraints on the ways the tree should be ornamented: the balls should come touching each other, and large balls should be at the bottom of the tree and small balls at the top. James had a difficult time ornamenting the tree. Nevertheless he was committed to the goal he had set up. At one point he needed to place a ball between two balls, as shown in figure 6.8a. His selection of the size for the ball was incorrect, and the ball was drawn overlapping the two other balls, as shown in figure 6.8b.

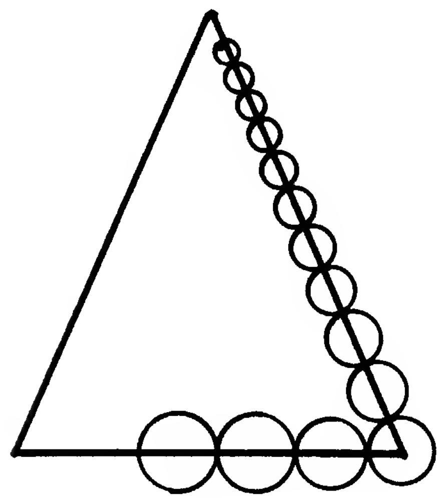

Figure 6.8a

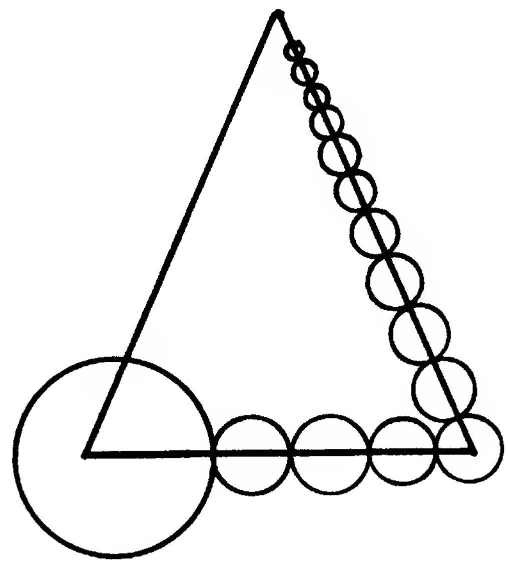

Figure 6.8b

This created a ridiculous situation in which it was difficult for James to admit that in fact his intention was to get the balls overlapping. The tree looked absurd and it was doubtful that James would have intended to spoil his previous work in this way. In short, he had to admit that what he had done was mistake. And he did! His reaction was to laugh, and, then, he articulated the cause of that mistake. The number he had used was too big and he wanted to correct it. I helped him to correct this bug, emphasizing that it was not a big deal to correct it. From that incident thereafter, James had less difficulty accepting mistakes, and showed interest in learning how to correct them.

James' acceptance of mistakes as constructive is an example of how the Logo activities can be used remedial tool. The remediation of his deficiencies happened in the process of developing Logo activities. It was not necessary to set up a special remedial program, as in the case of estimation of distance.

There are several point to be made about James' inability to accept mistakes. Since James had little confidence in his drawing capabilities, mistakes in this domain were threatening. However,

in other domains, such as writing, in which James was more confident, it was much easier for him to admit and correct mistakes. In his writing James was not afraid of making mistakes and correcting them later. For example, when he did not know the spelling of a word he would write down the phonetic representation of this word, and would continue. This procedure was adopted naturally, and allowed him to work independently. However, in his drawing when he did not know which command to use, or which number input to use in a command, he would interrupt his activities and would demand my attention. He was not willing to adopt the same strategy adopted in his writing, i.e., to try an approximate solution, and if the result was undesirable, to correct it later. This indicates that James' debugging technique used in his writing did not transfer to his drawing activities suggesting that debugging techniques have domain-specific properties, and do not necessarily and naturally transfer from one domain to another.

Another important point to be made refers to the function the computer played in James ability to admit mistakes. The computer allowed him to develop activities to which he attached personal value. James was proud of his computer work and liked to show it to people. These activities became something he wanted to present in the best way possible, since they revealed his mental capabilities, and his creativity. At the same time these activities, which could be interpreted as "serious business," were being developed in a way that looked more like *play*. In this context it was all right to make mistakes since their consequences were harmless. There was no drastic loss in making a mistake, the natural reaction to it was to laugh. This reaction was not peculiar to James. Lawler (1979) described similar incident when his 6-year-old daughter, Mirian, was drawing a girl. Mirian forgot to adjust the the Turtle's position, and the body of the girl came out attached to the girl's ear. Mirian laughed at it, and then indicated the reason for the mistake. That was Mirian's first noticeable situation in which she accepted her mistake and indicated interest in correcting it. The laugh, as Minsky (1980) has described, is an excuse to admit the absurdity of the action the person has taken, and seeing it as a joke indicates that in fact the person is aware of the mistake -- the laugh is the confirmation of that awareness.

James' Logo activities demonstrated that there is a imbalance between his writing and drawing skills. It showed also that his deficiencies were related to his inability to estimate distance, and to admit his own mistakes. These activities also indicated that James had developed a series of compensatory mechanisms to cope with his deficiencies. I wondered whether he would use similar mechanisms to cope with other spatial-related tasks. Thus, I asked James to perform a series of tasks. Following is a discussion of the results.

6.5 James' Ability to Perform Spatial-Related Tasks

The objective of this study was not to develop a complete profile of James' spatial-reasoning capabilities, but rather to gather information about James' ability to perform these tasks, thus complementing the findings of his computer drawing activities. I asked him to perform only a few spatial-related tasks: the seriation task, the village (or topographical) task, and the mental rotation task.

In the seriation task, as described in Chapter 4, James could not seriate four real sticks. He selected the sticks that were closer to his right hand, placed them on the line, and made no attempt to correct the order of the sticks. In the screen version of the task, James seriated four sticks, although he could not insert the three extra sticks. Thus, there was a difference in James' performance in the real and screen versions of the seriation task.

In the village (or topographical) task James had another surprising idiosyncratic performance. This task consists of placing a doll at different locations in a landscape model. The experimenter and the subject each have an identical model of the landscape. The experimenter places a doll successively at different locations in his model, and for each placement of the doll, the subject is required to place his doll in the same location on his own model. Nine locations were used, A through J, as shown in figure 6.9.

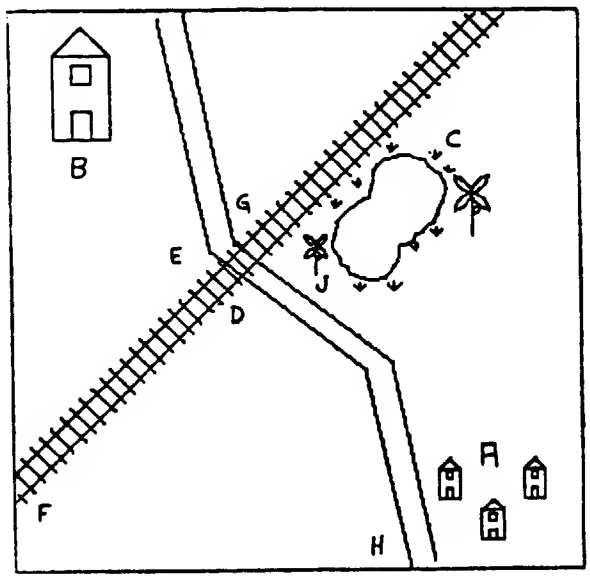

Figure 6.9

The test has two parts. In the first part, the models of both experimenter and subject are in the same north-south orientation. In the second part, the experimenter's model is rotated 180 degrees, and the subject's model remains in the original orientation. In the screen version of the task, the subject's model is drawn on the computer screen, and the doll is represented by the cursor, which can be moved by pressing one of the directional buttons on the computer keyboard. In the real version of the task James' strategy was to copy the experimenter's physical movements while moving the doll. This strategy worked fine while the two models were equally oriented. When the experimenter's model was turned 180 degrees from James' model, the same strategy did not work and led him to misplace the doll. He got only 3 out of 9 locations correct. In the screen version, James used a different strategy. He described aloud the location of the doll, and achieved a score of 8 correct placements out of nine.

It is interesting to notice that on the seriation task and on the village task, James' performances on the screen versions of these tasks were much superior to those on the real version. This suggests that the computer screen task seems to facilitate James' access to strategies that rely on his

strengths, probably because his physical weaknesses can be minimized. Also, on the screen seriation, the fact that he had to deal with one step at the time may have lead him to organize more efficient strategies to solve the task. On the village task, by turning the screen task into a linguistic task, he was able to improve his performance remarkably. On the real versions of these tasks his strategies were limited by his handicap.

James also performed a mental rotation task.[1] This task consists of discriminating two stimuli presented at different orientations. It was developed by Marmor (1975), who used two bears as the stimuli. She found that 5-year-old normal children could "mentally rotate" the bears. A computer version of Marmor's mental rotation task was developed, and the bears are drawn on the computer screen. The difference between the two bears is the bears' arms: one arm is raised and has a flag in it, and the other arm is down by its side. The left bear is always presented at a zero degree orientation, and the right bear is rotated clockwise randomly at 0 degrees, 30 degrees, 60 degrees, 120 degrees, and 150 degrees. The child has to press the D button if the bears are different, or the S button if the bears are the same. James' performance on this task was at chance level. He got 28 answers correct out of 60. James showed little understanding of the task, and he was not consistently able to distinguish the pair of bears in any arrangement (Laatsch, 1981). The results showed that: (a) there was a great discrepancy between James' and normal children's ability to mentally rotate; and (b) James made more errors than any of the nine other cerebral palsied children who performed the task. Laatsch (1981) indicated that an extended training period might have helped James to improve his error rate on the experimental test by providing him a chance to develop a strategy appropriate to his cognitive level.

These findings indicate that, first, depending upon the task, James is able to develop compensatory mechanisms to improve his performance. This was noticeable particularly on the screen version of the seriation and topographical tasks. In tasks that do not allow him to develop

1. This task was administered by Linda Laatsch, as part of her master thesis (Laatsch, 1981).

and use these compensatory mechanisms, he does perform poorly, relying on inappropriate strategies. Second, these observations indicate that depending upon the task used, James' evaluations might be misleading -- they may demonstrate James' deficiencies or proficiencies he may not have. However, the fact that he can develop and use this compensatory mechanism is an indication that he is capable of overcoming most of his disabilities if we help him to make use of these mechanisms.

6.6 Conclusion

James use of the computer to perform spatial-related tasks, to write, and to develop drawing activities indicated that: (a) there is a imbalance between his spatial and linguistic skills; (b) James' performance in spatial-related tasks are deficienties; and (c) some of these deficiencies can be improved either by providing him with the necessary experience or helping him to develop compensatory mechanisms to solve the task.

James demonstrated that his writing does not have the same disorganization, or type of mistakes that characterize cerebral palsied individuals' writing, as we observed in Mike's writing. James has good ways of organizing his ideas and has a top-down approach to deal with the problem of writing. This linguistic strength indicates that a vocational career could be designed around this skill. With the use of the computer James could improve his writing capabilities and utilize this strength as a way of making a living and becoming independent.

Another important result from James' use of the computer was that it made possible the diagnosis and remediation of two weaknesses: estimation of distance, and acceptance of his own mistakes. Also, the fact that James used the computer to perform tasks that required him to manipulate objects demonstrated that he is able to develop and use compensatory techniques to overcome many of his disabilities. Thus, designing of remedial programs for James should emphasize the development of compensatory strategies to solving problems.

Chapter 7

Kate's Case Study: Importance of Active Learning

Kate was a 13-year-old girl when she began participating in the Logo project, in October, 1979. She continued her work until the end of the 1982 school year, when the project ended. Kate is a spastic quadriplegic cerebral palsied girl, who has poor fine finger motor control, walks with crutches, and uses glasses to correct her nearsightedness. She is verbally alert, eager to interact with people, and her conversation shows a persistent intellectual curiosity. Despite her verbal skills, Kate has very poor writing skills and poor understanding of number and spatial concepts. In short, she is a child with limited cognitive skills in several domains.

The objective of this chapter is to show how Kate's computer activities can illuminate our understanding about learning. Kate's computer work can help us to understand the significance of the process by which facts are acquired and applied. My premise has been that learners should acquire knowledge actively. I will show that Kate's cognitive deficiencies are, at least, partially attributable to her passive role in gathering facts and her previous inability to participate in a learning environment in which she could use her capacities to their fullest potential.

7.1 Kate's Background

Kate was a 13 year-old girl in October, 1979 when she began to work with Logo. She was enrolled as a fifth-grade student in the Cotting School for Handicapped Children in Boston. She is a spastic quadriplegic cerebral palsied, with all four limbs mildly impaired. She is ambulatory with crutches, and she has poor fine finger motor control. Her written work is barely legible. She uses

glasses to correct her nearsightedness. She is very friendly, and eager to work with adults. She is verbally alert and does not hesitate to question people about events and objects around her.

Despite her verbal alertness, her cognitive function is very limited. Her verbal IQ score is 79, placing her in the dull normal range.[1] Her strengths are vocabulary and comprehension. However, her writing skills are poor. She is able to type declarative sentences, although she has problems organizing her ideas properly, as shown in these two essays she produced using the computer text-editor.

Crtimmiss
Hi got evere thning
Tip britri hari drier
Sary and a crres aracetrack
Draw

Hostage
I am happy that thay are home with their famle
They are home at lest frm I ran
52 American
The hostage came horm from Iran
Hostages were Blindfolded by the Iranians students
Wore terblue ublue

On the seriation task her performance was poor on both versions of the task. As described in Chapter 4, Kate was unable to achieve even the partial seriation which is ordinarily expected of a 5-year-old. On the real version of the topographical test, when the experimenter's model was turned 180 degrees from her model, Kate was able to place the doll in 2 correct locations out of 9. The mental rotation task, described in Chapter 6, was not administered to Kate because her performance on discriminating pairs of stimuli was far below criterion level. Even after four training sessions she was not able to learn to distunguish identical pairs or mirror-image pairs of

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1. The evaluator reported that the performance section of the WISC was not administered because of Kate's perceptual and motor deficits.

stimuli (Laatsch, 1981).

The school's evaluation reports indicated that Kate was a child who had difficulty with abstract reasoning and had to work with concrete objects. She also had great difficulty working independently. Kate's performance as a fourth-grade student was two to three years below grade level in all subjects. Her teacher reported that Kate "is a strong auditory learner who is able to grasp main ideas and detail if she interacts with the educational material auditorily, although the major area of concern is Kate's ability to work independently."

Kate was also being seen in the Resource Room for reading, language, and mathematics. An evaluation of Kate's mathematical skills, done in June, 1979 indicated that "Kate needs an approach by which she will produce the math concepts by herself through manipulative measures. She will comprehend math concepts if she can touch and form the math problem." Another report, written in March, 1980, mentioned that Kate's chief academic problems were "difficulty recalling and following a sequence of letters or operations. She needs constant assistance and cuing; has difficulty conceptualizing and manipulating ideas; has significant problems in visual areas of memory, perception, and motor control." This same report emphasized that Kate needed to learn through concrete material. "Kate learns best when material is presented on a concrete level in a consistent, repetitive manner."

The problem with these recommendations, however, is that Kate's hand motor skills are limited and she has great difficulty manipulating objects. For example, the performance section of the WISC was not administered to her, and the Bender Gestalt test could not be interpreted due to Kate's inability to draw. The evaluator attributed this difficulty "to organic insult and residual motor/perceptual deficits." These observations indicated that Kate had a great chance to benefit from the Logo activities. With the computer she would be able to exercise her spatial and numerical skills in a concrete way. Since she was able to type on the computer keyboard, her fine motor impairment would not prevent her from manipulating "objects" on the computer screen.

7.2 Summary of Kate's Logo Activities

During Kate's participation on the Logo project she had the opportunity to work with three different instructors: Gary Drescher, a member of the Logo project; Wanda, a staff member at the Cotting School Resource Room; and myself. Drescher used a series of tasks to investigate Kate's problem-solving techniques. He found that Kate's problem in commanding the Turtle seemed to be due as much to a lack of problem-solving strategy as to deficiency of spatial understanding per se (Drescher, 1980).

Wanda used the "Navigation Game," one of the tasks that Drescher had developed, to introduced Kate to Logo commands. The "Navigation Game" consists of making the Turtle a character in a story. Parts of the story scenario are drawn on paper and glued on the computer screen, and the Turtle is supposed to "visit" each of these places, according to a script that Kate would develop. By using the Logo commands FORWARD, BACK, RIGHT, and LEFT, Kate could command the "Turtle" to visit each of the different locations. Unfortunately, a record of Kate's activity during this period was not kept. However, by playing the Navigation Game she learned the Logo commands, the 90 degree turn for making squares, and to use reverse commands (i.e., FORWARD 100 produces the reverse effect of BACK 100.)

I began to work with Kate in February, 1981, and continued until the end of the 1982 school year, when the project ended. She had two sessions per week of approximately one hour each. During this period Kate had a chance to develop several projects, using Logo commands to direct the Turtle. The first projects were drawing figures that were made of squares. Each session she proposed a different configuration of squares and drew each square using Logo commands (rather than procedures to draw squares). The other projects were drawing a butterfly, using the LCIRCLE and RCIRCLE procedures that I provided her, and drawing a building, which she did not finish.

Kate's Logo activities indicated that she had great difficulty mastering the concepts involved in commanding the Turtle to either visit targets, or to draw a picture that she proposed. She needed

to repeat the same activity several times before she began to grasp the basic notions involved in the activity. Initially she would need constant guidance. With the repetition of the same task she would construct a series of rules that she would utilize to guide her performance. Kate also had difficulty trasferring some kinds of acquired knowledge from one activity to another. Those that she was able to transfer she discovered by herself; those which she used at the teacher's suggestion she did not transfer easily.

This brings up an important point: that knowing is connected to how one learns. In addition, it is important to be the "developer" of the ideas rather than the passive recepient of them. It is possible that Kate's low level of cognitive functioning is due to her passive role in the learning process. The following sections will illustrate this point.

7.3 Kate's Initial Logo Experience

Drescher used a program similar to DRAWING to introduce Logo to Kate. Her first activity consisted of commanding the Turtle to reach a particular target placed on the computer screen, as shown in figure 7.1a. The Turtle was commanded to move forward or back in the direction it was facing by pushing the key F or B on the computer keyboard. By pushing the R or L key the Turtle would rotate, about its central axis, to the right or to the left respectively. Thus, it was possible to command the Turtle to reach the target by using a succession of two simple steps: *turning* the Turtle to face the target and *moving* the Turtle in that direction.

Kate showed a very striking behavior pattern while commanding the Turtle to go to its "house", a drawing of a house pasted on the computer screen, as shown in figure 7.1a. First, she never oriented the Turtle spontaneously, or would persist in the wrong direction for a significant time after the error had become obvious. When Drescher took the role of the driver and asked questions like "what do you need to do now?", Kate knew the answer and would respond by hitting the R key to modify the Turtle's heading. However, her new heading would be in error in the opposite orientation by as much 45 degrees, as shown in figure 7.1b (Drescher, 1980).

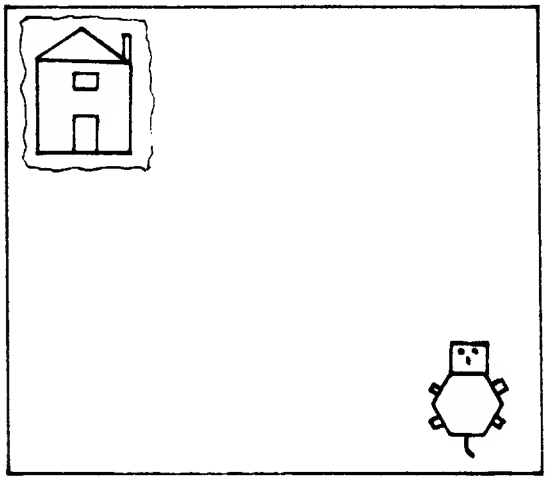

Figure 7.1a

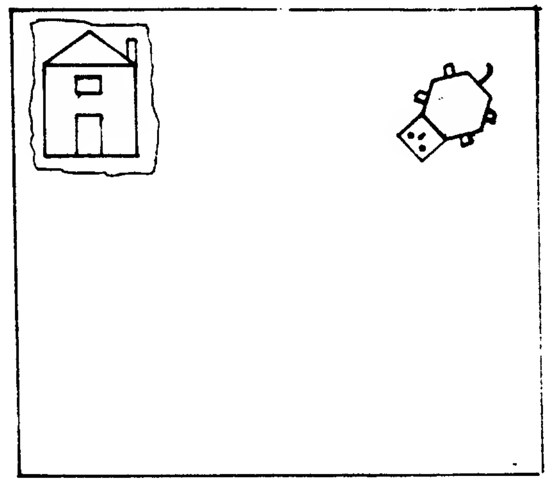

Figure 7.1b

The task of orienting the Turtle is one which that a 7-year-old child usually has no difficulty accomplishing. Kate not only had to be prompted to face the target but when she did the orientation of the Turtle was often incorrect. This discrepancy and the fact that Kate has neurological problems led Drescher to explore the cognitive developmental factors that contributed to Kate's inability to orient the Turtle.

There are several possible explanations for Kate's behavior. First, her knowledge about problem-solving techniques may not have been fully developed. She may not have acquired certain types of general knowledge which consequently prevented her from applying corrective actions when a particular plan was not working. Thus, she had to be reminded of what to do and her solution was often not appropriate. Second, her visual problems may have caused her some difficulty seeing where the Turtle was pointing, especially when the Turtle was too far from the target. In this case she may have adopted the strategy of orienting the Turtle towards the target and use mid-course corrections until the Turtle reached the target. She may have paid little

attention to the Turtle's initial orientation because even when its heading was off by as much 45 degrees, the Turtle could be made to reach the target by using a larger number of mid-course corrections. Third, Kate may not have acquired certain predictive skills involved in the task, e.g. to anticipate where the Turtle is going to be if it moves in the direction it is facing. This may be the result of not understanding causal (predictive) relations in her actions, not understanding certain spatial concepts, or both. Thus, there are several possible explanations for Kate's poor performance: lack of problem-solving techniques, e.g., debugging; lack of domain-specific skills, e.g., spatial notions; poor understanding of casuality, e.g., predictive skill; or visual impairment.

Drescher was particularly interested in investigating the first hypothesis: Kate's problem-solving skills. He used a series of spatial related tasks and language tasks. Kate's performance in each of these tasks allowed him to conclude that her poor performance was due as much as to a lack of problem-solving techniques as to a deficiency in spatial understanding per se (Drescher, 1980). He found that Kate could not invoke a plan of action on her own, did not know how to evaluate the current plan or replace failing plans with new ones, and could not identify an error and debug it on her own.[1]

Among the tasks that Drescher used, Kate enjoyed the "Turtle Navigation Game." In this game, as explained above, the Turtle is part of a story whose script Kate would suggest. While working with Drescher, Kate played the game by pushing the F, B, R, L buttons to command the Turtle's movement to each of the locations. During these activities Kate was able to develop an appropriate strategy to direct the Turtle to each location. Kate's better performance can be explained by the fact that (a) the script, a verbal cue, probably helped her to improve her performance; or (b) Drescher indicated that he advised Kate to "turn the Turtle to face the target,

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1. Later I used a modified version of the target game to evaluate Kate's notion of turtle orientation (Valente, 1982). This testing approach enabled me to identify Kate's strategies and to compare her performance with that of other cerebral palsied children. Kate's poor performance also reflected a lack of knowledge about certain concepts involved in the game, such as the ability to extrapolate the Turtle's position.

then move it forward to the target" which became the slogan "turn-then-move" which she applied with his assistance (Drescher, 1980). Thus, there were two factors that might have helped Kate to improve her performance in commanding the Turtle to a particular target. One was her good verbal skills. As noticed by the school's teachers, Kate is a strong auditory learner. Second, the repetition of the same rule might have helped Kate develop rules she used to play the game.

After several sessions playing the Navigation Game, Drescher introduced a new constraint to the game: the Turtle was not allowed to go off the screen edge (he eliminated the wraparound effect). In this new condition Kate's performance decreased dramatically, and she needed Drescher's cuing to help her to command the Turtle to reach a particular location on the screen. Thus, a minor change in the game's conditions was enough to create a new situation in which she could not apply any of the strategies she had acquired previously. Another explanation might be that she did not understand the "turn-then-move" strategy. This was a rule that Drescher had helped her to apply. It was not a rule that she had developed and was confident about. I decided explore this issue further.

7.4 Kate's Later Logo Activities

During the period that I worked with Kate, I adopted a different strategy. Instead of providing her with a piece of knowledge that she would memorize and then apply to her Logo activities, I decided to create situations in which she could develop knowledge on her own. For example, this was done by letting her work on drawings of pictures made of squares. She spent 22 sessions, of approximately one hour each, working on different projects using squares.

Kate's interest in developing these projects was motivated by another student's project. Kate noticed that this student was drawing "squares that get bigger and bigger", and she wanted to do the same. The first picture she drew is shown in figure 7.2a. Later she proposed and drew variations of the first picture, as shown in figure 7.2b.

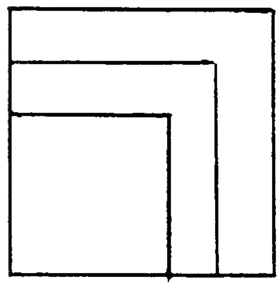

Figure 7.2a

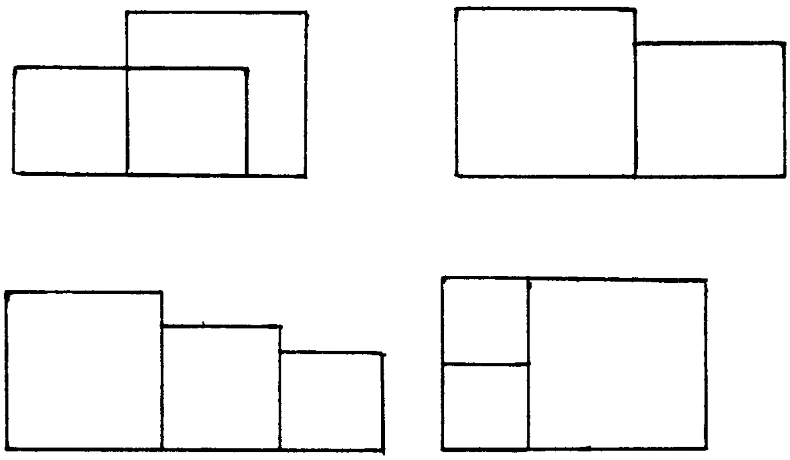

Figure 7.2b

From her work with Wanda, Kate had learned the Logo commands, how to use them in different situations, and how to use the 90 degree turn to make squares. She had no difficulty drawing the first square. However, to draw the second square she did not know which number to use for its side. She wanted to draw a bigger square than the previous one. She asked if 80 was bigger that 60 (the size or her first square). Then, decided to use 88.

Initially, the selection of size for the squares was a problem in which Kate needed assistance. She could not decide which number to select to draw a bigger or smaller square than the previous squares she had drawn. Gradually she was able to develop a rule to help her in choosing the size of squares: "a big number draws a big square, a small number draws a small square." She became very comfortable with this rule and demonstrated she could use it outside of her computer activity. This happened while she was performing a math task. Laatsch presented Kate with pairs of number and Kate had to determine which number was the larger. Kate was able to determine which number was larger in 9 out of 10 trials, and which number was smaller in 9 out of 10 trials. She explained to Laatsch that on the computer "when you want to make a square you push FD 100. If you want to make a smaller square, FD 70 can be used" (Laatsch, 1981).

Kate demonstrated that she could transfer (or invoke) her knowledge about bigness or smallness

to another project: drawing of a butterfly. I provided her with procedures to draw circles of different sizes (RCIRCLE and LCIRCLE) and she had no difficulty using different number inputs for these procedures to produce different size wings, as shown in figure 7.3.

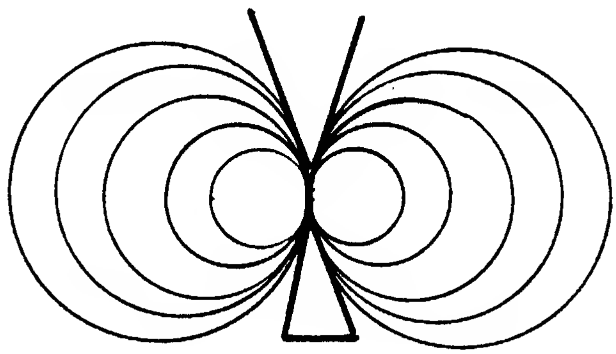

Figure 7.3

These observations also illustrate that Kate had acquired some predictive skills (small numbers cause small squares, big numbers cause big squares.) There was still some question about Kate's ability to transfer other knowledge from one situation to another. After the 1981 summer vacation, Kate showed interest in continuing to draw squares. This was her 19th session. I asked her what she knew about squares.She said "It's the same on all sides. Now I have to choose a number." She selected 99 for its side, and then proceeded using 99 as the input for the angle. She kept using 99 for all commands and got what she called a "flag." She could not understand how that picture had come out like a flag since she wanted to draw a square. This indicated that the knowledge about squareness was incompletely transferred. This same behavior was observed when she was drawing the picture of the building. Kate decided that its door should be a square. For its size she selected 90. The door came out too big. Then she decided to draw a smaller square and selected size 20. However, she proceeded to use 20 for its angles. It was not until I asked her

to draw different size squares that she could began to use 90 degree angles. Kate seemed to know that the sides of the square have to be equal and can be any number and perhaps thought that the angles, which also have to be equal, could be any number. I was not present when she was introduced to the "special angle" 90 degrees. But it is clear that she know "bigness," and transferred this knowledge, but not "squareness".

These incidents demonstrate that Kate can transfer, or invoke certain pieces of knowledge that she acquires through repetition. However, other facts that she uses in this same activity, which she appears to have mastered, either cannot be invoked or transferred to other projects.

7.5 Conclusion

Kate's computer activities provides us with the means for understanding her deficiencies in a meaningful way. Her difficulties seems to be related neither to her ability to retain knowledge (she has no problem retaining words and events) nor to her ability to invoke knowledge in general, but rather to her ability to invoke knowledge that she has not participated in constructing. Those forms of information that Kate tranferred most easily are those which she participated in developing. Drescher introduced the rule "turn-then-move" which appears intuitive enough to be helpful. We do not have a record of the way Wanda taugh Kate 90 degrees. For some reason, these concepts were not completely assimilated. Kate has always been on crutches. Perhaps body intuitions which she has are not those normally shared by others; maybe notions of turning and moving are hard for her to understand. But the fact that she was unable to work with these ideas -- to be an active participant in learning them -- was a crucial factor obstructing the acquisition of this knowledge. If this observation is correct, it can guide the design of more appropriate remedial programs for Kate.

Kate's behavior illustrates a theme which I have mentioned throughout the thesis: the learner has to be an active participant in the learning process. The learner needs to develop a personal attachment to knowledge, be able to build on it and transfer it to other domains. This can only happen if the learning environment is contextually meaningful for the learner.

Chapter 8

Summary of Results

The objective of this chapter is to present a summary of the results of the two studies described in previous chapters. I use some of these findings to revise the traditional methods of teaching physically handicapped children proposed in the literature.

8.1 Summary of Major Findings

The objective of the research was to develop a computer-based learning environment for children physically handicapped by cerebral palsy and to study several issues related to the use of this environment for diagnostic, educational, and remedial purposes. The study was motivated by the desire to better understand the intellectual and motoric deficiencies of cerebral palsied children and to use this information in the development of teaching methods to accommodate each child's particular needs. The aim of the study was to present a model for the use of computers with cerebral palsied children, thus enhancing the capacity of the computer as an effective and versatile educational tool as well as an invaluable aid in the diagnosis and remediation of the intellectual deficiencies these children may have.

Cerebral palsied children were selected to participate in the research because these children have

a disorder of movement and posture due to permanent but nonprogressive lesions of the brain occurring prior to the end of the first year of life. They are known to have cognitive retardation, which may be the result of either reduced interactions with the environment due to their physical handicap, or brain lesions which may affect motor areas as well as areas of the brain that support specific intellectual functions.

As consequence of their motor dysfunctions, cerebral palsied children have severe difficulty interacting within their physical and social environments. This has typically had significant negative impact on their education. First, these children's motor impairment makes understanding and evaluating their cognitive deficiencies quite difficult. It is hard to create interesting and challenging activities that these children can perform in order to evaluate their intellectual abilities. Second, education programs have not been designed to compensate for the cerebral palsied child's reduced experience with the physical world.

The research proposal was to create a computer-based environment to study alternative solutions to the problem of assessing and educating physically handicapped children. The goal was to provide children handicapped by cerebral palsy with the opportunity to develop interesting, challenging, and revealing activities that have an educational, diagnostic, and remedial purpose -- activities that could foster a deeper understanding of these children's intellectual abilities and provide these children with both a chance to acquire knowledge and to overcome their particular intellectual deficiencies.

The research was divided into two studies. One study was to investigate how cerebral palsied children could use a computer system for performing constructional tasks; i.e., tasks that require the child to manipulate objects while constructing a particular pattern.

A general computer system was developed for implementing a wide variety of these tasks. The aim of this system was to minimize the motor component involved in performing constructional tasks. The seriation task was implemented on this system. Nine nonhandicapped children from

4- to 6-years-old and thirty-two cerebral palsied children, between ages 11- and 19-years-old were tested with both the original and the screen versions of the seriation task. The results of this study showed that normal children were able to solve the seriation task at a much younger age than the children with cerebral palsy. However, the strategies used by cerebral palsied children to perform the seriation task were not different from the strategies adopted by normal children. This indicates that the cerebral palsied children's capacity to seriate is delayed rather than deviated when compared to the development of normal individuals. Further analysis of the data from the handicapped population showed that the cerebral palsied child's ability to perform the task was not significantly correlated with the child's age or degree of motor disability. Thus, for some of the children with cerebral palsy, intellectual capacity was not improving with age, and, furthermore, one could not assume that extensive physical impairment implies severe cognitive disability. These findings lead us to question the assumption that cerebral palsied children's intellectual development is correlated with their degree of motor impairment, and suggests that the task of educating these children requires individualized instruction and different teaching strategies. In addition, the results showed that the computer system is a useful tool for both assessment and development of these strategies.

In view of the finding that cerebral palsied children may need individualized instruction a second study was conducted. This study, which was the major part of the research, was an indepth exploration of the nature of cerebral palsied children's cognitive deficiencies. The objective was to investigate whether these deficiencies could be minimized by providing Logo programming experiences to these children. Three cerebral palsied children from the Cotting School for Handicapped Children participated in this study: Mike, a 17-year-old severe quadriplegic boy; James, a 13-year-old quadriplegic spastic boy; and Kate a 13-year-old diplegic spastic girl.

The results of the indepth study indicated that certain features of Logo became invaluable tool for diagnostic, instructional and remedial use with individuals motoricly impaired. Logo provided these children with an opportunity to engage in problem-solving activities and a chance

to play an active role in initiating and controlling their own activities. These activities had an educational purpose. With the computer these children developed tasks which provided them a way of acquiring new information, such as knowledge about trigonometry, number concepts, geometry, programming, English, and problem-solving (including planning, setting up goals, dividing goals into simpler subgoals, analyzing work in progress, modifying plans that do not work, and debugging).

These activities had also diagnostic and remedial purposes. The child's methods of problem solving were available for scrutiny, which helped to make the child's misconceptions concrete and specific. Combining information from a variety of Logo activities provided a powerful means of making a fine-grained analysis of performance in spatial, numerical, and writing domains. Through the use of the computer it was possible to identify weaknesses in Mike's writing skills and to reveal a great deal about his working style; his desire for perfection and elegance and his willingness to work out his ideas. The Logo activities made it possible for me to diagnose a discrepancy between James's writing and drawing skills. It showed that his abilities to estimate distance were very poor and his abilities to accept and correct mistakes in his drawing activities were much poorer compared to the debugging techniques he used in his writing activities. In addition, the Logo activities indicated that Kate's poor performance was related to her inability to invoke appropriate knowledge, and transfer knowledge from one situation to another. Although it was not possible to fully remediate her disabilities, we are in a much better position to make recommendations to guide the development of such activities.

Several remedial activities proved successful in helping children to overcome particular deficiencies that might be due to their lack of manipulatory experience. Mike's writing skills clearly improved as a result of the remedial writing activity. James's ability to estimate distance also benefited from the target game activity. Through the use of Logo, he was able to admit his mistakes and showed great interest in learning how to correct them. Kate's ability to work independently improved gradually. By being able to develop knowledge for herself she was able

to invoke it in different situations and be more independent of the people around her.

Another important aspect of the Logo environment is that it is a social environment because there is a great deal of interaction among the students. They share ideas, and programs, and we encourage them to help each other when they have a problem. There is also the opportunity to meet and interact with other people who come to the environment to find out what the students are doing. For example, Mike had to interact with several visitors who came to Cotting School. This became so important for Mike that he eventually developed a program to show all of his computer work using minimal typing effort. Mike also had a chance to introduce Logo to several other students at the school. This, as he said in his writing, gave him the opportunity to learn about people and about the projects they were interested in developing.

The Logo learning environment proved to be more than an environment to foster academic learning. It functioned as a physical therapeutic environment. Mike's computer activities were responsible for a remarkable improvement in the motor coordination ofhis hands and fingers.

The academic, social, and physically therapeutic improvements we observed in these children took place in an environment that down played the significance of perceptual and perceptual-motor development as the cause of these children intellectual disabilities. The Logo environment provided these cerebral palsied children with rich, interesting, and challenging activities for them to develop. Through these activities each child could express his intellectual potentials, creating a window into the whole person so we could see the interaction between cognitive and emotional functions. By providing a picture of the whole child we could deal with each child more effectively, tailoring activities to his personal interests and levels of cognitive capacity. The individualized educational approach that the Logo environment offers is more than just one-to-one instruction. It is individualized in the sense that we deal with each child's emotional and cognitive capacities.

The observation of cerebral palsied children's computer activities offered a magnified view of the

learning process, making it possible to identify the component's of a successful learning environment in an explicit way. My work with the handicapped serves to illustrate in a concrete way pedagogical issues which can be applied to the creation of learning environments for all people; how learning takes place in a computer-based environment; how the interaction between the student, the instructor, and the computer can help the student to acquire new knowledge; how to identify strengths and weaknesses in the students' thinking process; how to help them to use their strengths to overcome their weaknesses; how and when to intervene in students' activity to help them to overcome their difficulties without taking control away from the student; and how to design remedial activities to help the student to overcome specific difficulties or to acquire a particular forms of knowledge. In the following chapter I discuss a series of pedagogical principles that emerged from my work with cerebral palsied children.

8.2 Traditional Educational Methods Revised

The idea embedded in the Logo educational approach is not that we abandon the task-analysis or diagnostic-remediation methods in their entirely. Quite the contrary, these methods were integral aspects of the instructional techniques that I used with the cerebral palsied children. What I disagree with is: (a) the use of ready-made educational techniques or materials that are developed in laboratory; (b) the ultimate power that educators have to choose evaluation tests that can give an impoverished view of the child's intellectual abilities because they are neither able to identify the processes the child used to solve a task, nor do they permit evaluation based upon the child's interests; and (c) the adoption of remedial programs that are not particularly tailored to the child's needs. Logo, then, proposes an alternative education approach to overcome these drawbacks.

First, it must be mentioned that Logo is not a contrived environment, free of stimuli, as suggested by Cruickshank (1976b). The Logo learning environment can be a regular room with windows, pictures on the wall, tables, and chairs. The only necessity is the presence of a computer with the capability of understanding the Logo language. The Logo environment includes teachers,

students, and people coming in and out of the room; several activities are happening at the same time and there is a good deal of interaction among the students. Nevertheless, this does not mean that the students are not able to concentrate on their work. In spite of what Cruickshank and his co-workers would call background noise, the children in the Logo environment are able to concentrate because they are provided with a chance to do something that is both interesting and challenging. Thus, it is the computer-based activity that holds their attention, not a stimuli-impoverished environment. We did not get the students to concentrate on their work because they did not have anything else in the environment to attend to; rather we provided the students with a rich environment in which they could develop their curiosity by exploring the many different activities provided by that environment.

Another important aspect of the Logo environment is that the child acquires several skills simultaneously. This learning does not happen through formal lectures, but through activities the student develops. This is the key idea of the Logo method: students select the activities they want to develop, and they have control over it. The Logo instructor does not impose a particular task, or create artificial testing situations. The function of the teacher in Logo is to help the child to select a project that can be both fun and, at the same time, reveal important aspects of the child's intellectual abilities. This is accomplished through the use of methods such as task-analysis and diagnostic-remediation play an important role, although they acquire a different flavor in the Logo context.

The intention of using the task-analysis method in Logo is quite different from the goals proposed in the special education literature. The main objective of the task-analysis in Logo is to provide the instructor with information about the task the child is undertaking so that the teacher can be aware of the different strategies through which the task can be solved, and the different types of knowledge each of the strategies involve. With this information we can observe the child's performance and identify how he understands and approaches the task, those forms of knowledge the child has already mastered, and which forms of knowledge are deficient and might

be causing the child's failure. The task-analysis method in the Logo context is not used to empower the teacher with skills that are to be directly taught to the child, but to allow the teacher to become more knowledgeable about the task the child is developing -- the Logo instructor can then function more as couch than as traditional teacher.[1]

Once the child has selected a project to solve using the computer, this activity has a diagnostic purpose as well. I emphasized in Chapters 5, 6, and 7, in the indepth study of three cerebral palsied children using Logo, that the selection of the activities by the children themselves allowed me to get to know the individual potential in a much more realistic and meaningful way. This added a flexible and creative aspect to the diagnostic process that is lacking in the traditional psychological testing.

Another important aspect of the Logo activities as diagnostic tools is that we are not adapting the activity to accommodate the child's physical disabilities. The activity the child develops and its final result are the same for all children. The computer helps, then, to eliminate several difficulties in evaluating a physically handicapped child. First, we do not have to modify the task, neither transforming it into a multiple choice-type problem, nor eliminating important components to suit a particular disability. What we adapt is the way in which the child communicates with the computer. If a child cannot use a regular keyboard, we may provide him with a device with fewer and larger buttons. Once this is done, the activities children are able to develop depends only upon his own initiative and desire. Second, by not transforming a task that was supposed to be a performance task, we can understand the processes the child is employing to reach a particular solution. In fact, the nature of the Logo activities themselves make explicit a description of the problem-solving techniques the child is using. The instructions the child gives to the Turtle constitute a description oi the processes the Turtle will use to carry out the activity,

1. A person who couches athletes do not pour "skills" into the team members, but rather has to let the trainees learn the "game" on their own, while, at the same time, help to identify individual strengths and work with these strengths in order to conquer new domains.

revealing the steps in the child's thinking, the problem-solving style, and the child's intellectual curiosity. Thus, the activity of programming the Turtle provides a more complete picture of the child's potential than do most psychological tests. The case studies, described in chapter 5, 6, and 7, illustrated these points. Third, the final products the child produces with the computer can be as perfect as the child wants them to be. The child who is not able to draw a line, can produce through the computer a line that is as straight as any normal child could draw. This is an important factor to consider because in the Logo environment we are not asking the child to perform a task that will exposed weaknesses that he cannot cope with. The physical impairment, for example, is an inherent component of the condition of cerebral palsy and can prevent children from showing their true potential because it places them in an inferior starting position. Even before the testing begins we know that there are some things that the child will not be able to do. The child probably knows this also, creating a situation that can be detrimental to an accurate evaluation. Fourth, the Logo activities create an on-going evaluation process. Considering the number of adverse factors that can influence the evaluation of a cerebral palsied child, it is unlikely that the best estimate of the child's abilities can be made in a hurried testing situation. Calhoun and Hawisher (1979) recommend that tests are best conducted over a period of days to obtain a comprehensive picture of the child's intellectual and educational capacities. This extended testing period happens naturally in the Logo environment. In general, any Logo activity takes a few sessions to be completed. This creates a process in which the child is being constantly evaluated. Thus, by having the child choosing activities that expose him to different knowledge domains and that take several sessions to develop, we can form a much more complete picture of the child's interests, cognitive style, personality, as well as intellectual and educational strengths and weaknesses. This is happening in an environment that is not artificial, in the sense of being a contrived testing environment. The child is having fun, while the teacher assumes different functions -- a facilitator or evaluator -- depending upon the context of instruction.

The child's activities have also a remedial purpose. As previously mentioned, in the Logo environment remediation does not happen through programs that try to improve underlying

perceptual skills. Rather, as suggested by educators of the cognitive movement, we deal directly with the deficiency. When a concept deficiency is encountered -- such as estimation of distance, concept of angle, or concept of trigonometry -- the remediation techniques that I used was to deal directly with those deficiencies. It seems that it would be entirely inappropriate to prescribe remedial programs that are too far removed from the students' activities or ones are not directly related to what the student is doing. The remedial programs develop in Logo do not have the function to introduce new activities or concepts different from what the child is trying to accomplish, as in the perceptual-motor training programs. On the contrary, Logo remedial programs are effective because they engage the child in activities that are directly related to what the he wants to accomplish. This was the basic idea that guided the development of the target game and Mike's remedial writing programs. There was no perceptual-motor training program to help Mike cope with reversal of letters. Rather, the remedial program consisted of daily writing exercises emphasizing construction of sentences, paragraphs, and organization of ideas.

My suggestion is that we complement the traditional testing process and the traditional educational approaches with something that the child has interest in and is committed to develop. Hopefully, this will decrease the likelihood on an evaluation or an education which is totally under control of the diagnostician or educators. This will also enhance the possibilities of an education in which the child has some participation in the process of deciding which activity he should develop. This can help us to make the testing and the education processes of physically handicapped children much more realistic, flexible, and creative. To illustrate how this can be helpful in terms of dealing with these children, I want to share an incident that happened with Mike. In our initial encounter I asked Mike what he was planning to do after graduation from the highschool in terms of his vocational career. He said he wanted to be an accountant. I thought about that idea and there was no way I could see someone who could not write or work out things on paper functioning as an accountant. Having another person doing these activities for Mike,

was, in my mind, unrealistic and a waste of time.[1] However, during Mike's computer activities the idea of being an accountant proved to be something he could attain without any difficulty. His last computer project was a program to estimate prices of 21 different items that the printshop department of the Cotting School produces commercially. Mike's program can save one-tenth of the printshop manager's time, and it introduced several other desirable features to the calculation of overhead, such as minimizing the paper wastage. Mike's margin of error is within .01 percent of the estimate calculated by the manager. Today, Mike has several of his friends asking him to use Visicalc or to develop program on his Atari 800 so they can have the administration part of their small business done by a computer. This process has helped Mike show to the people around him, including myself, that he can be an accountant. He has also convinced himself. There is no psychological or educational approach that could have predicted that Mike could be an accountant. Quite on the contrary, these traditional methods would have shown the many things that Mike could not do; he would either spend the rest of his live working on them, or he would be placed in an institution because there was not anything he could do for a living. It is inconceivable to me that life choices of thousands of people like Mike are entirely dependent upon diagnostic tests and educational methods that we know to be inappropriate for physically handicapped individuals.

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1. At that time I was still naive, and I was using the same way of thinking that is very common among people who deal with physically handicapped children.

Chapter 9

Creating Learning Environments: Some General Principles

This chapter tries to integrate the themes of the thesis and the summary from the last chapter into a form which allows us to look at and evaluate the construction of learning environments. In addition, I provide some pedagogical principles which I can identify, in retrospect, as essential in guiding me through my work. While these principles came directly out of my work with cerebral palsied children, I feel that they are applicable to the development of any learning environment.

The chapter begins with a discussion of the three main components of a learning environment: the learner, the learning materials, and the instructor. In the case of the instructor, I have added a little twist. The research method which emerged from my work has become a model for teaching in the Logo environment. Therefore, these two issues will be discussed simultaneously. Finally, I discuss the pedagogical principles.

9.1 The Learner and His Materials

Papert says that "children are builders of knowledge using the materials in their environment" (Papert, 1980). When the materials are found in abundance the child is able to learn in a natural way.

These materials must have certain properties in order to be used by the learner. For example, in order for learning to be an active process the learner must be able to interact with and be in

control of his materials: the painter paints and sees what he has painted, the block-builder piles blocks and sees the results, etc. This points to two interesting aspects of the learning process. One is that the interaction must be predictable so that the effects of a learner's actions are identifiable; otherwise, the learner cannot get involved. In addition, when learners have an environment responsive to their own actions, they are able to operate with independence and responsibly by confronting the consequences of their actions and reflecting upon them.

The second is that the child should be able to decide which material he wants to work with -- which activity he wants to develop. When children decide what they want to do they have made a personal investment in that activity. Motivation emerges naturally from the learner's decision rather than by being artificially imposed by the environment.

Learners are different enough so that each one needs materials which reflect their inherent style of using them. Therefore, materials have to be numerous and flexible. Numerous, in order to accommodate a variety of intellectual interests, and flexible in order to respond to a variety of cognitive and emotional styles. The Logo learning environment provides a body of expandable materials that have the properties mentioned. For example, the turtle becomes the material which the child uses to build knowledge. By observing the turtle's behavior, the learner can modify and build on past results.

Logo also offers additional descriptive power. A Logo procedure is a description of the process the learner uses to solve the problem. Procedures can be designed to interact with each other to solve complex problems. More generally, the Logo language makes it easy to define procedures which can be structured and used in a variety of ways. Through the procedure, an educator can see the learner's style and how the problem-solving activity is organized: this provides a window into the child's mind.

The Logo project in the Brookline schools demonstrated that students approach learning with a variety of personal styles which are variations of two approaches: the top-down approach, where

the learner, having a propensity for planning, has a clear image of the final goal and the overall organization of the project and works from this to the detailed description; and the bottom-up approach, where the learner "tinkers" and begins with details and a vague notion of the problem's solution, climbing to an increasingly complex and structured result.

By observing different learning styles we became aware of the need for diversity, rather than uniformity, in the development of learning materials. It is my thesis that the handicapped have special needs. However, this is not to imply that normal learners do not. On the contrary, all children (and adults) have special needs: knowledge is always imperfect. Each of us has a constantly changing understanding of ourselves and the universe. Learning is the continual re-ordering and selection of acquired facts. Learning is theory-building andLogo is a language that promotes theory-building.

To summarize, this section has addressed two of the three components of a learning environment: the learner and the materials of his learning. I have described some characteristics that learning materials should have and illustrated the ways in which the Logo language meets these conditions. However, the quality of the relationship between these two components is fostered by the educator (parent, teacher, friend, etc.). The following section discusses the role of the educator in creating an environment for learning.

9.2 Research Methodological Cycle: A Model for Logo Educators

My approach in describing the educator's function is based on my own teaching techniques which are intertwined with my research method. They are really one and the same.

A learning session begins with the learner proposing a problem. In order to understand how to proceed it becomes necessary to evaluate both the learner and the proposed project. A good project is one that is interesting for the learner and, at the same time, intellectually challenging. This interest is expressed in the learner proposing the project in the first place. What remains is the development of a strategy for evaluating the project for its appropriateness -- so that it is

neither too easy nor too difficult for the learner to work on. Thus, the process of defining appropriate projects becomes a problem in matching the difficulties of the proposed project -- what I have described as the task analysis -- with the capabilities of the student -- the diagnosis of the learner's capacity to handle the task.

The task analysis is the process of dividing a project into its component tasks and to identify the intellectual domains which correspond to each of these components. The educator needs to be able to identify the subject areas, although he does not need to be an expert in each of these areas.

The diagnosis of the learner's ability requires information about the learner's intellectual, physical and emotional resources. Most of the time an educator has had a sufficient history with a learner to provide this information. Other times, the educator may need observations of the learner's behavior in different settings, or the use of relevant testing procedures. The function of this information is to assist the educator to develop teaching strategies rather than for grading or labeling the learner.

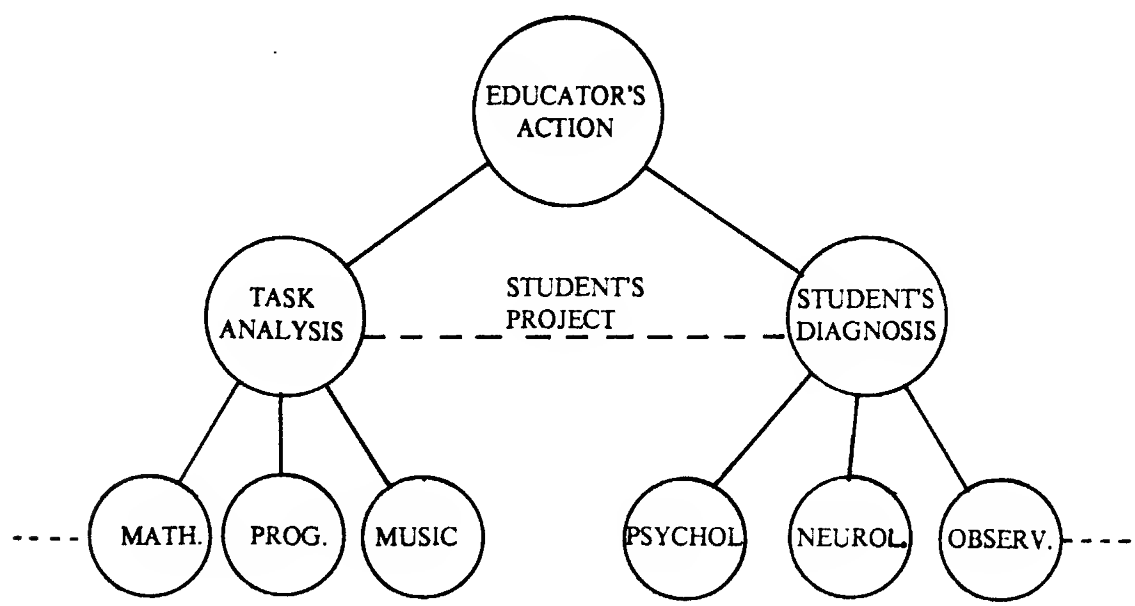

Figure 9.1

For example, Mike's desire to draw the letters of the alphabet required the evaluation procedure described above. I knew that for Mike to draw letters of variable size, he would need both concepts from trigonometry and algebra, and notions of proportion. After inquiring about his current math skills and knowing his programming skills, I might have proceeded in several different directions. I could have: (a) simplified the project, convincing Mike to use letters of fixed size; (b) asked him to learn about algebra and trigonometry; (c) provided Mike with a partial solution to the project which incorporated those parts which he didn't understand; or (d) provided Mike with a exercise sequence for handling just those mathematical concepts which were relevant to the solution of the problem. I chose the last option because I thought that Mike would have been discouraged by the simplicity of (a) and the complexity of (b). Option (c) would have been a "black-box" which Mike would have been unable to penetrate. Option (d) proved interesting because it was a way of applying mathematical concepts to a concrete situation.

James' target game is another example of remediation which was designed by matching the task and the learner's capacity. James had shown a deficiency in his ability to choose meaningful numbers for describing length. This deficiency was complicating his graphics projects. The solution was to address this problem separately using the target game.

In the process of understanding the learner, the educator is functioning as a learning theorist. The remediation introduced by the educator may not work if his theory about the learner is incorrect. The same is true if the educator encourages a project, proposed by the learner, based on the assumption that the learner has knowledge which he does not have. In this case, the educator's theory must be re-examined. This happened with Kate. I thought she had acquired more complete knowledge about squares than she had. I thought Kate could transfer what she knew about bigness and squareness to other projects. This proved partially true. Kate demonstrated that she could transfer the notion of bigness when she used bigger numbers to make bigger wings on her butterfly project. However, when she was unable to transfer knowledge about squareness to the building project she demonstrated that her problem-solving capacities were

less-than-complete.

In the process of revising the theory about the learner the cycle is complete. The educator has more information about the learner and more knowledge about learning, giving him the ability to provide more useful support in projects which the learner proposes.

To review, a learning environment is an amalgam of learner, learning materials, and an educator engaged in the process of matching the learner's skills with the variety of available learning materials. The educator's job is to participate in effective interaction. Logo is a special kind of material because it not only meets the conditions of being interactive and flexible, but its programs also become a useful language for documenting the learners' working style and skill. This provides the educator with additional tools for evaluating the nature of the learner's relationship to the environment and, thus, improves the educator's ability to support the learner.

9.3 Pedagogical Principles

In the process of working with cerebral palsied children, I found myself relying on several pedagogical principles. I have tried to generalize them so that they are applicable to all learning situations of the type described in this thesis. After my explanations, I offer specific examples from my research.

1. Blame the Learning Environment Rather than the Child

It is not the child who should be adapted to the environment; rather, it is the other way around. The instructor should attempt to build bridges between parts of the environment relevant to the child's growth. Logo provides mechanisms for creating these bridges -- adding to the environment special materials. The instructor can provide bridges from the child to the environment through careful intervention.

James showed some interest in writing a weekly newspaper and I provided a special text-editor to facilitate his desire. At a later date, I tried to use his experience as a "newspaper editor" -- where he corrected the layouts and spelling errors -- as a metaphor for debugging programs.

2. Respect the Child's Dream

Throughout the thesis I have proposed that we will be in a much better position to understand the child's intellectual strengths and weaknesses if the child is developing an activity in which he is interested. However, the fact that the child is in the position to choose his activities does not mean he is in a position to be able to develop them. The child may select a project that he does not have the knowledge to carry out. The educator's function should not be one of destroying that *dream* but one of helping the child to adjust the degree of complexity of the project to a more realistic level.

James wanted to draw a Christmas tree. However, I knew that the project was too complex for him to handle from scratch (given, also, certain time constraints.) I developed a collection of procedures -- pieces of the tree -- which James used to assemble it. This is an example of scaling a project for a learner.

On the other hand, "scaling" can also mean "scaling up." Mike's clock project is a good example. He wanted to draw the face of the clock but I encouraged him to make it a working clock, with hands that moved according to the internal clock of the computer.

Mike was also interested in doing a tic-tac-toe project in which the computer would be a contestant. While I am sure that he could handle the project now, the scope of the project was much too ambitious at the time. My solution was to trim the project by making the computer a passive, rather than an active, participant.

3. Rely on Experts for Additional Support

It is unrealistic to think that educators can know everything. Teacher training programs that attempt to do this result in educators learning too little about too many things. The solution, then, is to encourage educators to build people-networks -- experts, colleagues, friends and students -- to provide them with the necessary knowledge so that they can make effective decisions.

For example, I solicited the help of a linguist in the evaluation of Mike's writing. Throughout my

work, I frequently took advantage of the numerous professionals in the MIT community. They were happy to be able to help and provide their expertise.

4. It is All Right to Learn from Students

A learning environment is like a research environment; communication is good when colleagues can freely share ideas, no matter how unrefined. A student in a learning environment is a less experienced expert; yet, on occasion, roles can shift to the mutual benefit of student and educator.

I found my interaction with students in the Logo environment to be more challenging when a student was able to come up with something that I didn't know. For example, when Mike was developing the ESTIMATE program, we had a communication problem because I did not know the printing terminology and how a particular phase in the printing process would effect the cost of the final product. Mike took me through the printing shop and showed me all the steps involved in producing a printed document.

5. A Surface Problem can be a Symptom of a Deeper Problem

Logo helps provide the educator with a window into the child's mind, but one in which there are many rooms. If a child resists an educator's strategy for dealing with a problem, the educator should consider a change in strategy.

James shifted his goals. My attempts to discourage him from doing so was met with resistance. The real problem was his fear of admiting mistakes which, in turn, was connected to his poor self-image. Helping him to develop strategies for correcting mistakes improved his self-confidence and willingness to stick with a goal.

As another example, it has been a common procedure to infer cognitive limits from physical and emotional disabilities. The results of the seriation task, described in Chapter 4, indicate that the ability to seriate was not significantly correlated with age or degree of motor impairment. The indepth study, using Logo with Mike, James, and Kate confirmed these results. Kate is less

physically disabled than James. They both are the same age; nevertheless, their ability to develop Logo activities was different -- James' projects were more elaborate than Kate's. Therefore, psychological evaluations provide incomplete diagnostic information.

6. Look at the Child as a Whole Person

Most of the psychological and educational evaluations see the child as a "subject" who is able to solve certain tasks, and has certain deficiencies. Consideration of other variables, such as the child's desires and the child's working style, is seen as "contaminating the data." However, these evaluations fail to identify the cause of the child's deficiencies. They may identify what the child is not able to do, but they may not indicate the causes of the deficiencies or the possible sources of the solution.

In recalling the case study on Mike, we don't just see a subject learning a task; rather, we see the importance of knowing the role his desires, motivations, creativity, and sense of self played in shaping his intellectual growth.

7. Use People's Strengths to Attack Weaknesses

This must be one of the oldest educational principles. However, it must also be one of the hardest educational principles to practice. Most of the evaluators try to identify the learner's deficiencies. This is related to the educational philosophy which states that "to educate someone is to eliminate deficiencies." However, we may find that, once deficiencies are recognized, solutions emerge from looking at the skills students have and their confidence in applying them.

For example, a compensatory mechanism which James' case study illustrates was his ability to translate a spatial-related task -- e.g. a topographical task -- into a language task in order to use his linguistic skills to cope with his difficulties with spatial reasoning.

8. Learning Two Things can be Half as Hard as Learning One

And, I might add, twice as exciting!

The educational principle which assumes that learning takes place by presenting bits of information that are hierarchically sequenced implies that learning two things can be twice as hard as learning one. Natural learning, however, is rarely acquired in this way.

A good example is how Mike learned basic trigonometry. It was not a process in which he had to learn a sequence of concepts such as algebra, proportion, and trigonometric functions. All these different concepts were learned at once, one supporting the other and all used as necessary background knowledge to his alphabet-drawing project.

9. Jose, Apply These Principles to Yourself

Educators are often accused of more deficiencies than any person deserves. The educator should be patient with himself and have faith in his instincts. The educator should also be willing to get support from friends, colleagues, and students.

We compliment educators when their enthusiasm and conscientiousness causes them to take their work home, but often we do not encourage them to bring their home to work. Large problems become more manageable if we can bring all that we value in ourselves to solving the tasks in which we are engaged.

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Appendix

Subpart of the Pultibec System for Assessment of Child's Handicap

The lower and upper limbs disabilities of each cerebral palsied child was classified according to the the items U (Hand) and L (Locomotion) of the "Pultibec System for the Medical Assessment of Handicapped Children" (Lindon, 1963).

The grades for the upper limbs are:

1 - Competent use of hand and fingers within normal limits of speed, dexterity, coordination, and ability to hold and grasp an object.

2 - Near normal competence in use of hand and fingers with reasonably competent results in tasks performed, but slower than grade 1. Certain skills requiring fine lightly controlled movements can be accomplished in a reasonably competent way. Coordination only slightly affected. There is an ability to write.

3 - Slow execution of task with addition of significantly reduced coordination and/or unwanted movements resulting in a lowered standard of competence in work requiring dexterity. Fine movements, such as writing, is usually impossible but the subject is able to use a hand for eating.

4 - Movements reduced to significantly greater extent. Speed, dexterity and coordination are very limited. The subjects' ability to grasp is limited. They need help with eating, dressing and washing.

5 - Movements grossly reduced in usefulness. Hand and fingers used only in a supportive role.

6 - Hand and fingers useless for practical purposes.

The grades for the lower limbs are:

1 - Able to use lower limbs in a completely normal way with normal variations of speed and dexterity.

2 - Able to walk or run but with less than normal dexterity and speed. Distances usually traversed in everyday life are not a problem. Has some kind of gait.

3 - Able to walk reasonable distances at a moderate pace only with the help of stick or elbow crutches but not with armpit crutches.

4 - Able to walk only short moderate distances at a slow pace with the aid of armpit crutches.

5 - Able, with very close supervision, to walk a few steps. Able to stand still holding or when supported. Wheel chair is necessary when help is not available.

6 - Unable to walk. Wheel chair bound.